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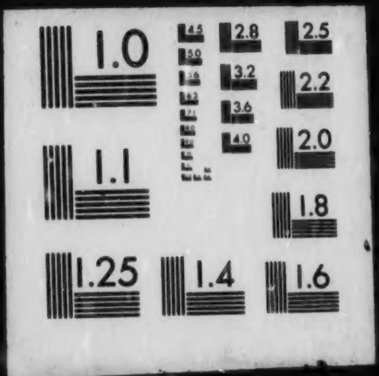
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User's Manual for the M.I.T. Transient Water Quality Network Model - Including Nitrogen-Cycle Dynamics for Rivers and Estuaries

Massachusetts Inst. of Tech., Cambridge

Prepared for

Corvallis Environmental Research Lab., Oregon. Marine and Freshwater Ecology Branch

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This user's manual contains a review of the theoretical background for the one-dimensional, real-time, nitrogen cycle model, a detailed discussion of the computer program including a complete listing of the program, and an example of the application of the model to hypothetical estuarine and river systems.

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Including Nitrogen-Cycle Dynamics for Rivers and Estuaries

by

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FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere.

This report concerns one aspect relating to the distribution of variables in a well-mixed, coastal plain, estuary. Interested users should contact the Project Officer for program listings.

A. F. Bartsch

A. F. Bartsch
Director, CERL

ABSTRACT

In July 1975, "A Real Time Model of Nitrogen-Cycle Dynamics in Estuarine System," by Tavit O. Najarian and Donald R. F. Harleman (Technical Report No. 204, R. M. Parsons Laboratory for Water Resources and Hydrodynamics, Department of Civil Engineering, M.I.T.) was published. This study presented the development of a water quality engineering model for nitrogen-limited, aerobic estuarine systems. The uniqueness of the model lies in its application of real-time hydrodynamics, that is, the proper specification of mass transport due to changes in magnitude and direction of flow with time in tidal systems. The model is intended to be used in engineering decisions regarding the degree of eutrophication due to distributed and point source loadings in estuaries.

This user's manual contains a review of the theoretical background for the one-dimensional, real-time, nitrogen cycle model, a detailed discussion of the computer program including a complete listing of the program, and an example of the application of the model to hypothetical estuarine and river systems.

This report was submitted in fulfillment of Grant No. 800429 by Professor D.R.F. Harleman under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period from July 1975 to June 1976, and work was completed as of July 1976.

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LIST OF SYMBOLS

A	cross-sectional area
A	a constant whose value depends on the nature of the deposits (Equation 3.40)
A	$b_{core} + (b_{total} - b_{core})d'$ (Figure 3.1)
A_{core}	conveyance area, $= b_{core}d$
A_s	surface area
$A_{storage}$	area of section that does not participate in conveyance, $= (b_{total} - b_{core})d'$
A_x	coefficient of horizontal eddy diffusivity
A_y	coefficient of horizontal eddy diffusivity
a	a constant
a_1	ratio of nitrogen to chloraphyll-a
BOD	Biochemical Oxygen Demand
b_{core}	width corresponding to conveyance area
b_{total}	total surface width of channel
$b(x)$	total surface width of the channel
C	Chezy coefficient
C	carbon (Figure 2.1)
C	cloud ratio (Equation 3.7)
C	concentration of C-BOD (Equation 3.10)
C-BOD	Carbonaceous Biochemical Oxygen Demand
CSTR	continuously stirred tank reactor
C	concentration of phosphorus in water (Equation 2.5)
C_g	filtering rate of zooplankton
C_{min}	concentration of NH_3-N above which NO_3-N uptake rate is minimum

c	concentration of storage variable in ppm
c	maximum grazing rate (Equation 3.33)
c	c(x,t) actual concentration of DO (Equation 3.41)
c_i^n	computed concentrations of water quality variables at nodal points
c_L	concentration of species in the lateral inflow
c_L'	concentration of species in the point source
c_s	saturation concentration of DO
$\dot{c}$	time rate of change in the concentration of a storage variable, i.e., $\frac{\partial c}{\partial t}$
c(s)	the value of the variable at a distance s from the upstream node of the element
D	dissolved oxygen deficit
D	a constant concentration at which P_1 equals zero (Equation 3.33)
$\underset{\sim}{D}$	assembled system matrix
$\underset{\sim}{D}_i$	element matrix
D_{P_j}	$= k_2T + C_gZ_j$
DEM	dynamic estuary model
DO	Dissolved Oxygen
DOD	dissolved oxygen deficit
DON	Dissolved Organic Nitrogen (N_7)
d	core depth
d'	average depth of storage area
d_c	depth to centroid of core area
E	dispersion or diffusion coefficients

E_L	longitudinal dispersion coefficient, $E(x,t)$
E_N	natural light extinction coefficient
E_p	Phytoplankton self-shading coefficient
$E(x,t)$	temporally and spatially varying dispersion coefficient
E_T	Taylor's dispersion coefficient
$\bar{E}_{x,y,z}$	dispersion coefficient in ft^2/sec
E_z	maximum rate of ingestion (Equation 3.35)
e_a	atmospheric vapor pressure
e_s	saturation vapor pressure
$\underset{\sim}{F}$	assembled system matrix
$F_{A,B}$	flux of species across a section
$\underset{\sim}{F}_i$	element matrix
$F_{2,1}$, $F_{3,1}$	conversion factors of NH_3-N to algae 1 and algae 2 biomass (Equation 2.17)
$F_{3,1}$	conversion factor between C_1 and C_3 (Equation 2.13)
$f(W)$	wind function
G	rate of zooplankton grazing (day^{-1})
$G_{It}(I,T,f,h,k)$	the functional relationships of the growth rate and solar radiation I, Photo period f, water temperature T, depth H, and light extinction coefficient k
G_{P_j}	growth rate of phytoplankton
g	gravitational acceleration (Equation 3.3)
g	zooplankton grazing rate in $(\text{gram zoopl-C/m}^2)^{-1}(\text{day})^{-1}$ (Equation 2.8)
H	$H(x,t)$, depth of flow
h	depth from water surface to horizontal datum

I	rate of ingestion per unit concentration of grazer (Equation 3.35)
I_o	incident solar radiation at the water surface
I_s	optimum solar radiation intensity
k	extinction coefficient (Equation 2.4)
K	estuary dispersion parameter (Equation 3.5a)
K	time constant for transformation process (Equation 2.1)
$\underset{\sim}{K}$	assembled system matrix
K_c	rate of C-BOD decay (Equation 3.10)
K_{C-BOD}	oxidation rate of carbonaceous organic matter
K_i	half saturation constant for ith storage variable
$\underset{\sim}{K}_i$	element matrix
K_s	half-saturation constant
K_1	half-saturation concentration for NH_3-N
K_3	half-saturation concentration for NO_3-N
K_4	half-saturation concentration for Phyto-N
k	empirical constant (Equation 2.12)
k_c	half-saturation constant for carbon (Equation 2.15)
k_{c_1}	half saturation constant for NH_3-N uptake by algae 1 and algae 2 (Equation 2.17)
$k_{d,1}$	decay coefficient of C_1 (Equation 2.13)
$k_{d,1}$	oxidation rate of NH_3-N to NO_2-N (Equation 2.17)
$k_{d,2}$	decay and ammonification of detritus
k_e	extinction coefficient

k_e'	natural extinction coefficient
k_ℓ	half saturation constant for light intensity (Equation 2.15)
k_{mn}	half saturation concentration of inorganic nitrogen
k_{M_p}	half-saturation constant for phosphorus
k_n	half-saturation constant for nitrogen (Equation 2.15)
k_p	half-saturation constant for phosphorus (Equation 2.15)
k_r	reaeration coefficient (Equation 2.13)
k_{re}	rate of reaeration
k_s	characteristic constant concentration (Equation 2.16)
k_t	concentration of limiting nutrient at which uptake rate $= 1/2\ V_{max}$ (Equation 2.11)
k_2	rate of natural death of phytoplankton
L	length of estuary (to head of tide)(Equation 3.5a)
L	width of field at distance y from diffuser (Equation 2.12)
M_1	mortality rate (Equation 2.14)
m	multiplying factor for bends and channel irregularities
m	conversion factor (Equations 2.3 and 2.4)
m	multiplying factor (Equation 3.5a)
m	constant coefficient (Equation 3.24)
N	concentration of living organisms (Equation 2.1)
N	Nitrogen (Figure 2.1)
N	nutrient concentration (Equation 2.9)
N	1-reduction factor (for phosphorus)(Equation 2.5)
N_i	concentration of N-cycle variable $i = 1,2,\ldots,7$
$N_i(t)$	concentration of N-cycle variables at any time t

N_i^{in}	initial concentrations of N-cycle variables at time t = 0
N_i^o	concentration of N-cycle variable in influent discharge
N_{IN}	concentration of inorganic nitrogen
N_{P_2}	concentration of PO_4-P
NH_3-N	Ammonia Nitrogen (N_1)
NO_2-N	Nitrite Nitrogen (N_2)
NO_3-N	Nitrate Nitrogen (N_3)
N_1	Ammonia Nitrogen (NH_3-N)
N_{1_c}	NH_3-N concentration beyond which NO_3-N uptake by phytoplankton is minimal
N_2	ammonia-nitrogen concentration (Equation 2.18)
N_2	Nitrite Nitrogen (NO_2-N)
N_3	Nitrate Nitrogen (NO_3-N)
N_4	Phytoplankton Nitrogen (Phyto-N)
N_5	Zooplankton Nitrogen (Zoopl-N)
N_6	Particulate Organic Nitrogen (PON)
N_7	Dissolved Organic Nitrogen (DON)
n	number of adjacent elements (Equation 2.13)
n	Mannings friction coefficient (Equation 3.4)
n	constant coefficient (Equation 3.23)
P	phosphorus (Figure 2.1)
P	phytoplankton population (Equation 2.2)
P	concentration of phytoplankton in terms of limiting nutrient concentration in phytoplankton (Equations 2.10 and 3.33)
$\bar{P}_h$	euphotic depth-averaged photosynthetic rate (Equation 2.2)

P_1	threshold level of phytoplankton at which the grazing rate falls to zero
Phyto-N	Phytoplankton Nitrogen (N_4)
PON	Particulate Organic Nitrogen (N_6)
Q	instantaneous tidal and freshwater rate of flow, $Q(x,t)$
Q_L	point source discharge rate
q	dispersive flux term at interior nodes
$\bar{q}$	prescribed dispersive flux boundary condition
q_L	lateral inflow per unit length
$\bar{q}_{x,y,z}$	instantaneous (tidal and freshwater) flow velocities
R	rate of respiration (Equations 2.2 and 2.13)
R	uptake of limiting nutrient by phytoplankton (Equation 2.9)
R_B	rate of oxygen uptake by benthal microorganisms
R_h	hydraulic radius
R_{jk}	rate of transformation of element nitrogen from storage i to storage k
$(R_{max})_{34}$	maximum NO_3-N uptake when NH_3-N concentration is zero
$(R_{min})_{34}$	minimum NO_3-N uptake at high NH_3-N concentration
R_o	respiration rate at 0°C (Equation 2.7)
R_{opt}	rate when temperature is optimal
R_T	biological reaction rate at temperature T (Equation 3.21)
R_T	respiration rate at T°C (Equation 2.7)
Red_1	growth rate reduction factor due to NH_3-N scarcity in the environment
Red_2	growth rate reduction factor due to NO_3-N scarcity in the environment
r	reduction in the rate of biomass production due to variation in solar radiation intensities (Equation 3.25)

r	a constant, 0.069 (Equation 2.7)
r_e	time rate of increase in the mass of a species due to external sources per unit volume
r_i	time rate of increase in the mass of a species due to transformations per unit volume
S	substrate concentration (Equation 2.16)
S	concentration of salinity or dye (Equation 3.9)
S	point source of a species in $\frac{r_e}{\gamma}$ (Equation 4.9)
S	rate of mass injection of a species per unit volume (Equation 4.33)
S'	distributed species source
$(S_{ex})_i$	external sources and sinks of the nitrogen cycle variables
$(S_{in})_i$	internal sources and sinks of the nitrogen cycle variables which results from transformations
S_{P_j}	source term for phytoplankton biomass = $(G_{P_j} - D_{P_j})P_j$
S_1	settling rate (Equation 2.13)
S.W.	seawater
S	salinity, S(x,t)
S_o	ocean salinity
s	normalized non-dimensional distance to the location of the variable from the upstream node (Equation 4.17)
$\dot{s}$	$= s/s_o$ where s(x,t) is the spatial and temporal distribution of salinity in ppm
T	temperature
T	tidal period (Equation 5.11)
TR_{ij}	transformation from storage variable i to storage variable j
T_a	atmospheric temperature
T_{max}	temperature above which $R_T = 0$
T_{opt}	optimum temperature

T_s	water surface temperature
t	time
U_f	fresh water through-flow velocity
$U(t)$	temporal velocity in the channel
U_T	maximum tidal velocity
u	average cross-sectional longitudinal velocity of conveyance area (A_{core}) (Equation 3.3)
u	$u(x,t)$ tidal velocity (Equation 3.5)
u_o	maximum ocean velocity at the ocean entrance
V	1-reduction factor (for phytoplankton sinking)(Equation 2.6)
V	uptake rate (Equation 2.16)
V	volume of node (CSTR) (Equation 2.13)
V	cross-sectional average flow velocity (Equation 3.44)
V_{max}	maximum uptake rate
v	velocity in y direction
WHD	waste heat discharge
x	longitudinal direction
x_L	end point of the reach
x_o	origin of the reach
$\dot{x}$	$= x/L$
y	lateral direction
y_2, y_3	percent of ammonia uptake preferentiality by algae 1 and algae 2 respectively
y_5	percent of NH_3-N release in decay of detrital biomass

Zoopl-N	Zooplankton Nitrogen (N_5)
Z	concentration of zooplankton in terms of carbon, nitrogen, or total biomass (Equation 3.33)
Z	gram Zoopl-C/m^2 (Equation 2.8)
Z_j	concentration of zooplankton biomass in the jth volume segment
z_1	depth of euphotic zone (Equation 2.4)
z_2	depth of mixed layer (Equation 2.6)
α	ammonia preference factor
$\alpha_1, \alpha_2, \alpha_3$	constants to be evaluated
γ	specific weight
γc	(specific weight) (specific heat) in BTU/sec-ft.
$\Delta_{m-2,m}$	length of the first or last element
∇	Vector differential operator
$\delta(x^*)$	delta function centered at x*
η_m	computed ocean boundary dispersive flux
Θ	a temperature constant
ρ	fluid density
ρ_{01}	phytoplankton sinking
ρ_{02}	fish predation on zooplankton
ρ_{13}	ammonia uptake by phytoplankton
ρ_{14}	nitrate uptake by phytoplankton
ρ_{15}	nitrogen fixation
ρ_{21}	zooplankton grazing
ρ_{32}	zooplankton respiration
ρ_{40}	upwelling of deep oceanic waters rich in NO_3^--N

ϕ_a	incident atmospheric radiation
ϕ_{ar}	reflected atmospheric radiation
ϕ_{br}	long-wave radiation from surface
ϕ_n	net flux of heat
ϕ_c	heat flux due to conduction
ϕ_e	evaporative heat flux
ϕ_r	net radiation
ϕ_{sr}	reflected solar radiation
ϕ_s	short-wave incident solar radiation
μ	growth rate (Equation 2.13)
$1/d_p$	concentration of phytoplankton at which $I = 2/3\ E_s$

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Mr. Aldo Alvarez, Research Assistant in the Ralph M. Parsons Laboratory, assisted in the preparation of the test cases used in this document. Computer work was done at the M.I.T. Information Processing Center.

I. INTRODUCTION AND HISTORICAL DEVELOPMENT

1.1 Introduction

This manual describes the development and the application of a real time water quality model for estuarine ecosystems. The developed model solves the one-dimensional continuity and momentum equations to generate the temporal and spatial variations in the tidal discharges and elevations. This information is used in the solution of the conservation of mass equations for the water quality variables. The solution of these equations employs an implicit finite element scheme to determine the temporal and spatial variations of the following water quality variables:

1) Salinity-coupled to hydrodynamics through a state equation,
2) Temperature-coupled to transformation rates,
3) Carbonaceous BOD-coupled to dissolved oxygen equation,
4) Nitrogen-cycle variables - intra-cycle and extra-cycle coupling
    N_1 - Ammonia-N
    N_2 - Nitrite-N
    N_3 - Nitrate-N
    N_4 - Phytoplankton-N
    N_5 - Zooplankton-N
    N_6 - Particulate Organic-N
    N_7 - Dissolved Organic-N
5) Dissolved oxygen-coupled to CBOD and nitrification,
6) Fecal coliform.

The structure of the model is a closed matter flow loop for the element nitrogen and it is developed under the assumption that the dominant activity in the estuarine ecosystem is aerobic and that nitrogen alone limits the growth of organisms. The predominant characteristics of the model include the following:

1. Strict adherence to the mass conservation principle as applied to the element nitrogen.
2. The ecosystem model is coupled with a real-time hydrodynamic transport system as opposed to a tidal-average or slack-tide approximation.
3. The structure of the model was formulated such that the level of complexity would not be too complex to the point of diminishing returns, nor too simplified to the point where rate-governing parameters must be determined by curve fitting the available field data.

1.2 Historical Development Through 1975

This model combines the work of many investigators. A brief history begins with the development of the hydrodynamic section of the model done by Gunaratnam and Perkins (1970). They developed a high accuracy numerical scheme for the solution of unsteady flow in open channels using weighted residual or Galerkin Techniques (Finite Element Method). They also developed the framework for the application of this solution to a network of open channels.

Dailey and Harleman (1972) developed a numerical model for unsteady water quality transport also using Galerkin Techniques. This model was combined with the hydrodynamic model of Gunaratnam and Perkins and the resulting combined model incorporated the proposed network formulation. The Dailey and Harleman network model provided for the prediction of transient velocities, elevations, and concentrations of salinity, temperature, B.O.D. and D.O. The salinity intrusion calculations were based on the work by Thatcher and Harleman (1972) which provided a longitudinal dispersion relationship depending upon gross stratification conditions, thereby freeing the solution from field data requirements for the determination of dispersion coefficients. The hydrodynamic calculations are weakly coupled to the salinity distribution through the salinity-density relationship. Temperature calculations were based on the excess over equilibrium simplification and the B.O.D. - D.O. calculations were made with the B.O.D. solution feeding forward to the D.O. equation. No formal publication of a user's manual was made due to monetary restrictions and the knowledge that modifications to the Dailey and Harleman model would be forthcoming.

The temperature portion of the model was reformulated by Harleman, Brocard and Najarian (1973) so as to incorporate more generally applicable meteorological parameters into the model and release the constraint of the constant surface heat decay coefficient and equilibrium temperature hypotheses.

Applications of the model led to a variety of modifications, the broadest application being to the St. Lawrence River and Estuary, a study sponsored by the Canadian Departments of the Environment and Transport and Quebec Service de Protection de l'Environment and Ministere des Richesses Naturelles. This study was executed by Surveyer, Nenniger & Chenevert Inc. and Carrier, Trottier Aubin (1973, 1974). The application included provisions for control structures and the addition of other water quality parameters including an interactive nutrient model. Thatcher, Pearson and Mayor-Mora(1975) have described the application to both riverine and estuarine portions of the St. Lawrence River from Cornwall to Montmagny, a distance of 275 miles (443 km).

The most recent modification to the network model is the incorporation of a real-time nitrogen cycle model by Najarian and Harleman (1975). This most recent addition consists not only of the calculation of the nitrogen-cycle dynamics in terms of seven forms of elemental nitrogen, but also has recast the numerical water-quality solutions of Dailey and Harleman in terms of a higher order finite element. The need for a published user's manual was recognized by the National Environmental Research Center, U.S. EPA, Corvallis, Oregon and their support has enabled the documentation of the model at this stage of its development. It will undoubtably be further modified by its users - but this manual will serve as a necessary common benchmark.

II. DESCRIPTION OF THE MODEL

2.1 Overview of the Modeling System

An overview of the modeling system can be formulated in terms of the basic function of the model. If one considers the "knowns" and "unknowns" of this modeling system, it is apparent that the model consists of known geometry, initial conditions and boundary conditions. Its function is to produce a solution consisting of the flow, surface elevations, and water quality concentrations (or temperature). Thus in a structured sense the modeling system can be regarded as, (1) a means of mathematically describing the geometry of the river or estuary system; (2) a means of mathematically specifying the initial conditions of flow or of water quality in the model; (3) a means of mathematically describing the boundary condition of flow and of water quality; and (4) a means of mathematically calculating a solution to the appropriate equations so that the model can predict the unknown hydraulic and water quality parameters.

The purpose of this report is to explain to the user of this modeling system how to prepare input data so as to successfully specify the above four enumerated constituents of the model. The user can specify a branching and/or looping network of channels called reaches. Each reach can be of variable cross-section along its longitudinal axis. Storage volumes are provided for along the reach and any number of concentrated or distributed water quality loadings can be specified along each reach. The flow regime can be that of a river system, steady or time-varying or it can be that of an estuarine system with an unsteady tidal elevation driving the circulation at the ocean boundaries in combination with the upstream inflows. As many applications require a repeating tidal condition and steady tributary inflows this condition is especially provided for as the quasi steady-state tidal condition.

The model which accomplishes these calculations is available as a FORTRAN IV program with 4445 source statements (not counting comments) and consisting of 47 routines. The reason that this computer program is so large is twofold. First it must be recognized that for the model to be useful to many users, it must be able to describe a wide variety of geometries, initial conditions and boundary conditions. In order to provide this flexibility the computer program must be extensive in terms of the number of different kinds of conditions for which it can provide a solution. Secondly, as described in Section 1.2, the computer program is the result of many different researchers and is a developmental program. To this date there has been no possibility to stop all development and, with the enormous leverage of hindsight, reprogram the entire computer system with efficiency and simplicity as aims. The result is a collection of many different subroutines, some of which may seem awkward. The authors acknowledge the fact that such a computer program is far from the ideal of today's programming techniques; i.e., structured, modular, and top down programming, however it has been very useful in its present form.

2.2 Hydrodynamic Equations

The derivation of the unsteady one-dimensional continuity and momentum equations used in this model may be found in Daily and Harleman (1972). The continuity equation is:

$$B\frac{\partial h}{\partial t} + \frac{\partial Q}{\partial x} - q_L = 0 \qquad (2.1)$$

and the momentum equation is:

$$\frac{\partial Q}{\partial t} + u\,\frac{\partial Q}{\partial x} + Q\,\frac{\partial u}{\partial x} + g\,\frac{\partial h}{\partial x}\,A + g\,\frac{A\,d_c}{\rho}\,\frac{\partial \rho}{\partial x} + g\,\frac{Q|Q|}{A\,C^2 R_h} = 0 \qquad (2.2)$$

where

B = channel top width in ft.

h = depth from water surface to an arbitrary horizontal datum in ft.

Q = cross-sectional discharge in ft^3/sec

q_L = lateral inflow per unit length in ft^3/sec/ft

u = average cross-sectional longitudinal velocity in ft/sec

g = gravitational acceleration in ft/sec^2

R_h = hydraulic radius in ft.

A = the cross-sectional area where there is longitudinal flow in the channel in ft^2

C = Chezy coefficient

ρ = fluid density

d_c = depth to the centroid of the channel cross-section in ft.

The Chezy coefficient is expressed in terms of Manning's roughness n. This permits the natural roughness of the channel to be specified as a function of x. The spatial and temporal variation of the friction coefficient is expressed by:

$$C(x,t) = \frac{1.49}{n(x)}[R_h(x,t)]^{1/6} \qquad (2.3)$$

The cross-sectional areas used in the momentum equations and the mass conservation equations are not necessarily the same. In fact, they differ with the description of channel schematization. Estuaries may have embayments which store water under the varying tidal stage. These regions do not contribute to the conveyance in the longitudinal direction. Therefore, the cross-sectional area used in the momentum equation is the area where there is longitudinal flow and the top width used in the continuity equation is the total top width. On the other hand, the total cross-sectional area is used in the mass conservation equations to reproduce the correct volume of the estuary for mixing pollutants. Detailed considerations of storage and conveyance volumes are considered in Section 3.1.4.

The numerical solution of the continuity and momentum equations is carried out in real time, i.e., the tidal discharges Q(x,t) and cross-sectional areas A(x,t) are computed in intervals of the order of half an hour. The fundamental reason for the use of a real time formulation of the transport processes in the ecosystem model as opposed to the more "economical" tidal average or slack-tide formulations lies in the fact that the temporal and spatial distribution of the mass concentrations of species are neither uniform nor steady within a tidal period in an estuary. Furthermore, the natural upstream advection of species from the point of discharge during flooding tide can only be simulated with 'real time' hydrodynamics. A 'real time' hydrodynamic model can simulate the tidal flushing of pollutants at the ocean boundaries of estuaries. It can also simulate the lag in tides between the downstream and the upstream reaches in a relatively long estuary.

2.3 Water Quality Equations

Since in streams and estuaries the dominant direction of flows is longitudinal, the assumption can be made that at any x, a lateral and vertical homogeneity in the concentration of the variable under investigation exists. Thus, we may write the one-dimensional form of the conservation of mass equation with internal and external sources and sinks as:

$$\frac{\partial}{\partial t}(Ac) + \frac{\partial}{\partial x}(Qc) = \frac{\partial}{\partial x}\left(A\,E_L\,\frac{\partial c}{\partial x}\right) \pm \frac{A\,r_i}{\gamma} \pm \frac{A\,r_e}{\gamma} \qquad (2.4)$$

where

c = concentration of a variable, $c(x,t)$ ppm

$\frac{\partial}{\partial t}$ = instantaneous time rate of change

$\frac{\partial}{\partial x}$ = rate of change in longitudinal direction, x

A = cross sectional area of the stream, $A(x,t)$, ft^2

E_L = longitudinal dispersion coefficient, $E_L(x,t)$, ft^2/sec

r_i = time rate of increase in the mass of a species due to internal transformations per unit volume, lbs/sec/ft^3

r_e = time rate of increase in the mass of a species due to external sources per unit volume, lbs/sec/ft^3

γ = specific weight of the fluid, lbs/ft^3

Q = instantaneous (tidal and freshwater) rate of flow, $Q(x,t)$, ft^3/sec

III. APPLICATION

3.1 Schematization of Natural Geometry

The first step in mathematical modeling is a numerical description of the study area. Charts, maps and other data sources should be assembled in order to provide the necessary geometric data. As the numerical description is an approximation of the actual waterbody, decisions must be made as to the degree of approximation required by the particular study being made. A trade off between detail of representation and higher cost of modeling is inevitable. In some cases it may be useful to make more than one schematization of the study area, the two having distinct levels of approximation. This section presents the steps required to perform a schematization.

3.1.1 Establishing a Network of Reaches

The study area must be represented by a network of reaches of variable area. The points of confluence of these reaches (nodes) are mathematical points, that is to say they do not have any volume of water associated with them. With his chart or map of the study area in front of him, the user should establish a longitudinal axis for each of the reaches which define his network. For some very large systems it may be desirable to set up subnetworks. The longitudinal axis of each reach constitutes the fundamental reference for all the calculations of hydrodynamics and of water quality for that reach. The reach geometry will then be further specified by selecting representative cross-sections along the longitudinal axis. A typical network for Cork Harbour, Ireland, is shown in Figure 3.1. Due to the fact that the illustration does not show depth contours the rationale for choosing the particular network

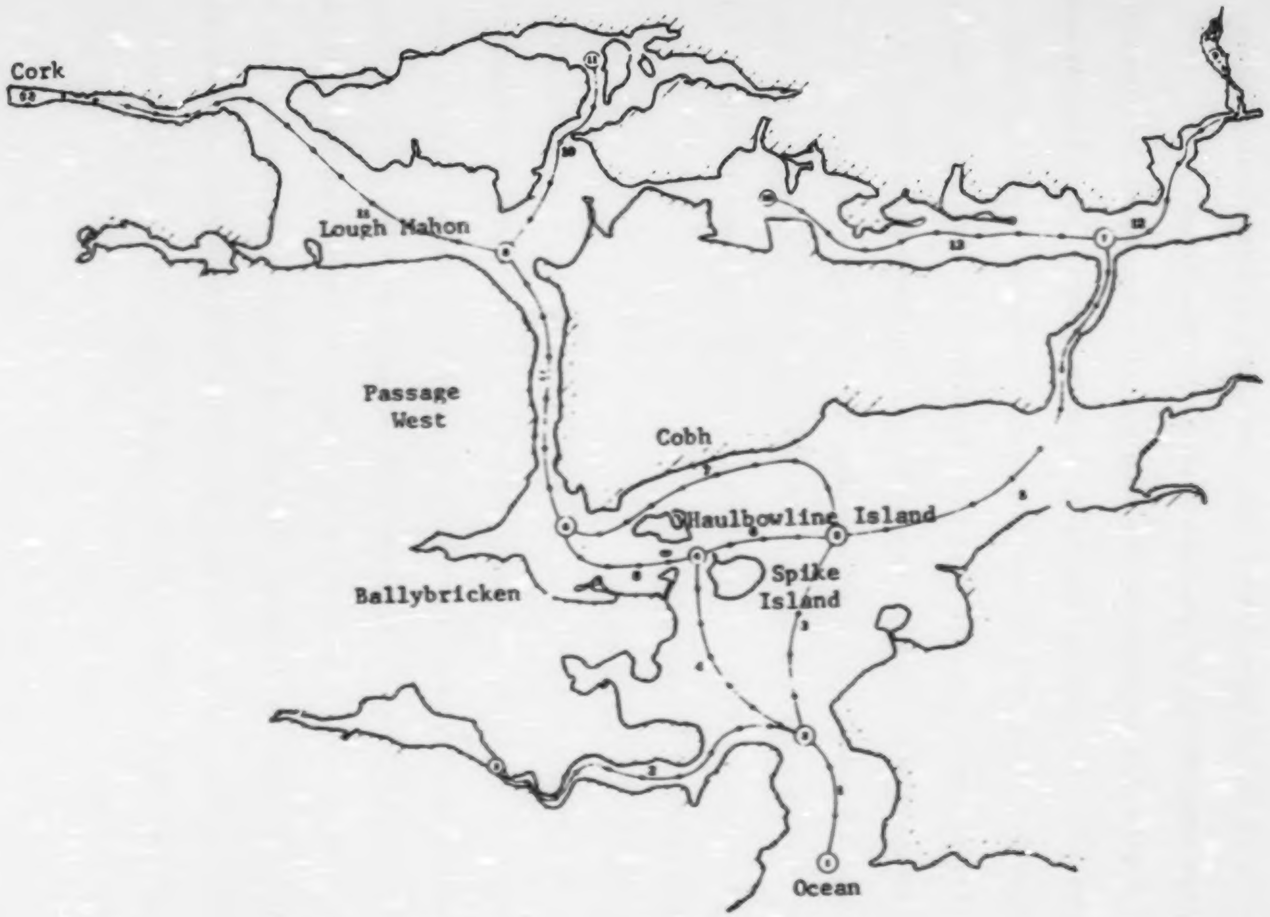

Cork
Lough Mahon
Passage West
Cobh
Haulbowline Island
Spike Island
Ballybricken
Ocean

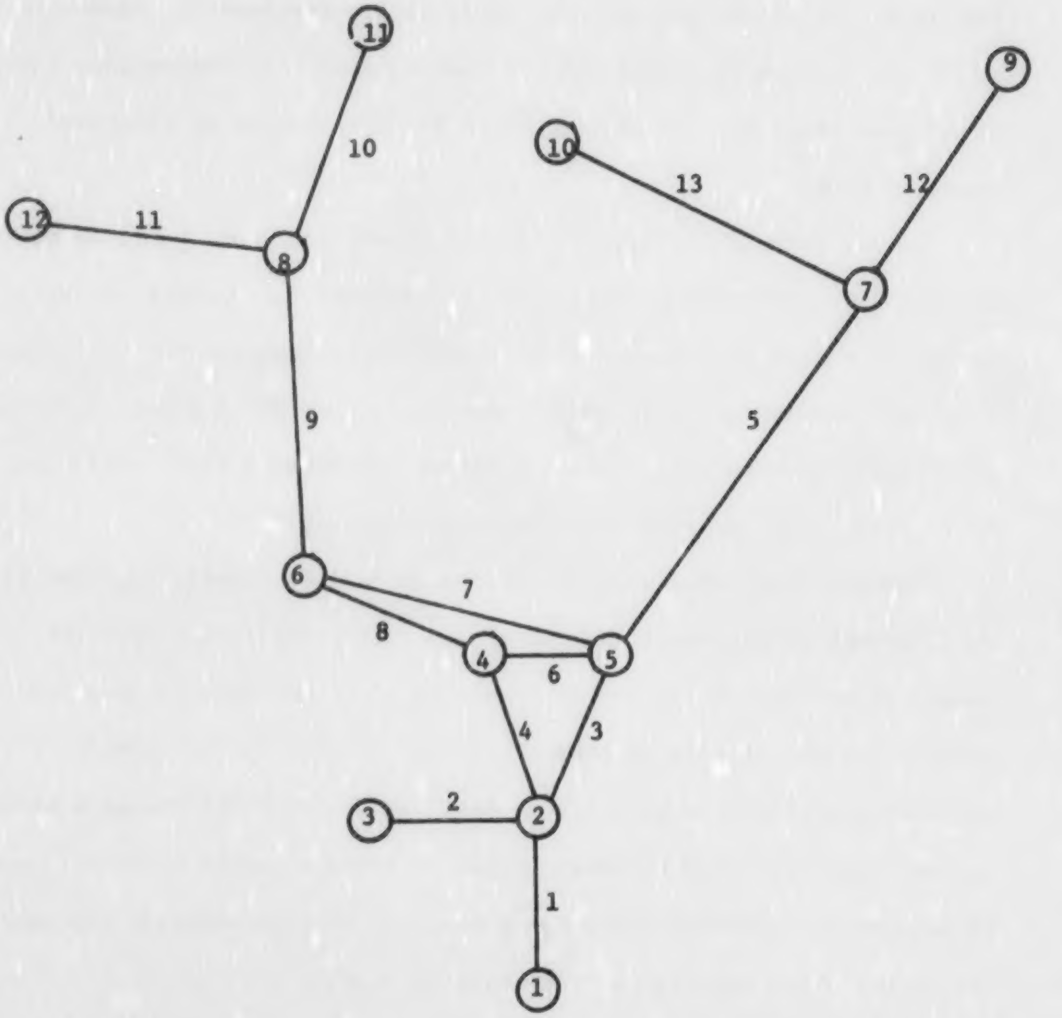
FIGURE 3.1 NETWORK FOR CORK HARBOUR STUDY

is not apparent. Each application has its required level of detail and this level will determine the selection of reaches. In some cases water areas can be represented as adjacent storage areas of a reach instead of being incorporated into the model as additional reaches. Storage considerations are described in Section 3.1.4.

Figure 3.2 illustrates the topology of the network corresponding to Figure 3.1. The reaches and nodes must be clearly identified by numbers. Reaches are identified by numbers which are entirely arbitrary and need not follow any particular sequence, however the nodes must be numbered sequentially starting with the number 1. Furthermore, economy of computation results if the node-numbering system is designed so that the difference between the node numbers at the beginning and at the end of each reach is kept to a minimum. The example shown in Figure 3.2 shows a maximum difference of 4.

3.1.2 Vertical Datums

In many cases the geometric data describing the waterbody will be relative to a single horizontal datum. In cases where an estuary includes a significant upstream or riverine portion, the nautical charts may refer to some local water plane such as local mean low water or local mean river level. Depending on the extent of the waterbody, different charts may refer to different datums. In such circumstances, and in the obvious case of river systems, the vertical datums must be known to the user so that he can correctly relate all vertical geometry to a common datum.



11
10
9
10
13
12
12
11
8
7
9
5
6
7
8
4
5
6
4
3
3
2
2
1
1

FIGURE 3.2 TOPOLOGY OF CORK HARBOUR SCHEMATIZATION

3.1.3 Establishing Cross-Sections for Each Reach

The M.I.T. Network Model defines the geometry of the water body along a particular reach by interpolation between the cross-sectional data submitted by the user. In this manner the user need define only as many cross-sections as he finds necessary to represent the principal geometric features of the reach. For a canal this could be the specification of one single cross-section. In cases where it is not deemed necessary to represent the cross-section in great detail, a rectangular, trapezoidal, or double rectangular schematization may be selected. Otherwise, the transverse properties of the reach can be described by an irregular cross-section.

In selecting the number of cross-sections the user should be guided by the knowledge that the computer program will interpolate linearly between the defined cross-sections. This means that in order to correctly represent geometrical features of importance such as an abrupt widening of a reach, the user must define a number of cross-sections sufficient to represent the change in the cross-sectional area.

The user must also specify a computational increment, Δx, that is small enough to represent changes in geometry. There is always the danger of defining a Δx that is larger than the distance between two cross-sections. A rule of thumb could be that the Δx for hydrodynamic calculations should be at least as small as the shortest distance between any two user-specified cross-sections. The hydrodynamic calculations will be made using a computational increment, Δx, that is constant for each reach, but which may change from reach to reach.

The water quality calculations permit a variable Δx, thereby allowing finer resolutions in those portions of the waterbody where concentration gradients are the largest.

With the exception of the cross-sections that are rectangular, trapezoidal, or circular, (Figure 3.3) the cross-sections must represent not only the ability for conveying water but also the ability to store water. That is to say for many cases it is necessary to provide for volumes of water which do not participate in the longitudinal momentum equations, but none the less must be accounted for in terms of the continuity equation. Thus a provision has been made called an irregular cross-section whereby the user can specify the cross-sectional area that is divided into a conveyance or core area and a non-conveyance or storage area. Figure 3.4 illustrates the two irregular cross-sections provided, Figure 3.4a being the general irregular cross-section with storage area, and Figure 3.4b being the double rectangular cross-section. The double rectangular cross-section is also referred to as an irregular cross-section of constant top width, the completely irregular cross-section being referred to as an irregular cross-section of variable top width.

The parameters used for the hydrodynamic water quality calculations are functions of depth. For the definition of simple cross-sections this dependency upon depth can be calculated by the computer program itself. But for the completely irregular cross-section of varying top width, the cross-section must be defined so that the variation of its parameters as a function of depth is specified by the user.

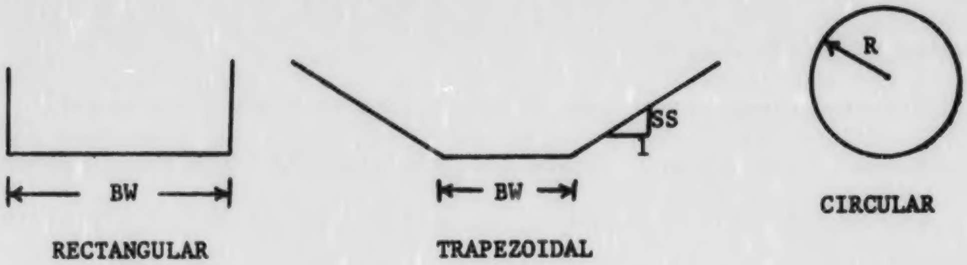
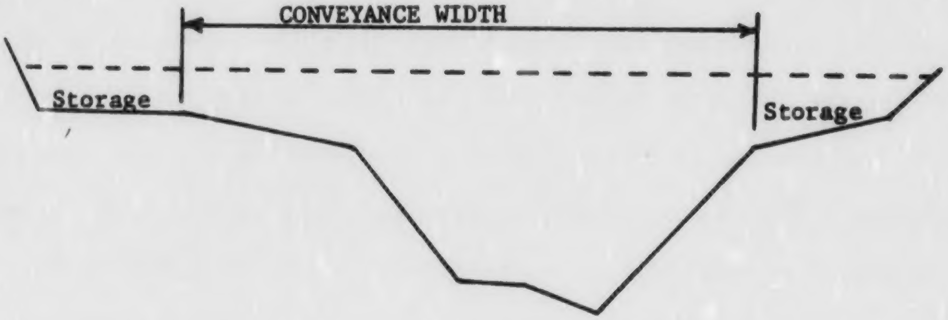
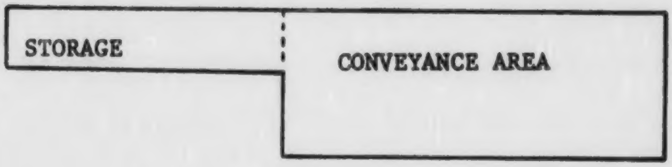

BW
RECTANGULAR
SS
1
BW
TRAPEZOIDAL
R
CIRCULAR

FIGURE 3.3 SIMPLE CROSS-SECTION TYPES


CONVEYANCE WIDTH
Storage
Storage

a. Irregular with storage. (Topwidth varies with water surface)


STORAGE
CONVEYANCE AREA

b. Double Rectangular (Topwidth Constant)

FIGURE 3.4 IRREGULAR CROSS-SECTIONS WITH STORAGE

3.1.4. Cross-Sections for Storage and Conveyance

The need for cross-sections which provide for both a conveyance (core) area and a storage area is satisfied by either the constant or variable top width irregular cross-section. These cross-sections are those illustrated in Figures 3.4a and 3.4b. The need for storage considerations comes from two distinct aspects of schematizing the 3-dimensional waterbody to a system of parameters all related to specified locations along a longitudinal axis. This one-dimensional schematization requires a provision for portions of the cross-section which corresponds to water that is not moving in the longitudinal direction at all, or in some cases is moving relatively slowly as compared to the water in the conveyance area.

3.1.4a Schematization to Double Rectangular Section

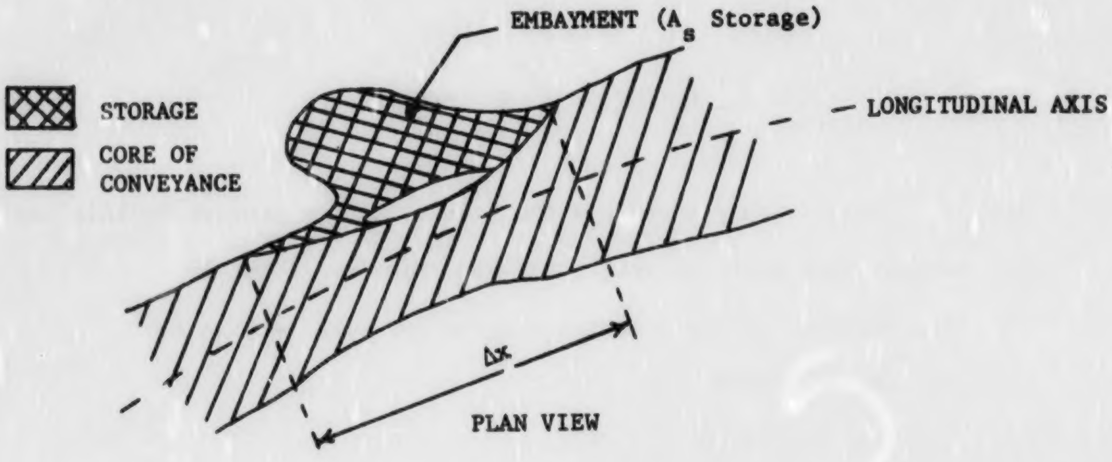
The plan view of Figure 3.5a shows a typical estuary reach containing an embayment. The water in the embayment does not participate in the longitudinal tidal transport, however, it fills and empties with the change of water surface elevation. The embayment acts as storage, and in cases where the surface area of such embayments is a significant percentage of the total surface area, the schematization should represent the storage action.

The schematization employed is based on the determination of a conveyance or core area which is defined in terms of a width b_{core} and a depth d_{core}. This requires that the user determine an average cross-sectional area and width for the conveyance area. This area is then represented in rectangular form by dividing it by the average width to obtain the depth, d.

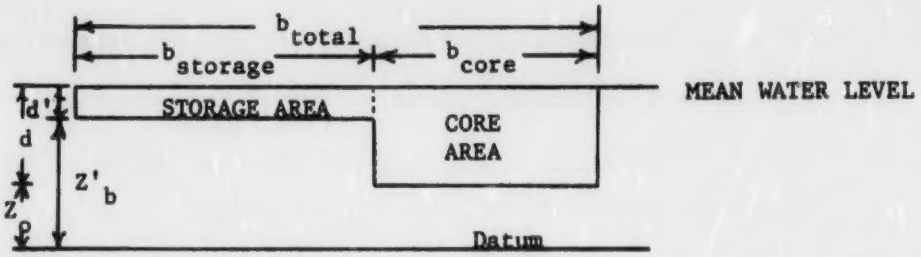
Figure 3.5b shows how this core area is joinged to a storage area. To define the storage area it is necessary to define a depth of the storage area, d'. This depth, multiplied by the surface area of storage, $A^s_{storage}$, yields a volume of storage $V_{storage}$. To obtain an equivalent cross-sectional storage area $A_{storage}$, the volume of storage is divided by the length between cross-sections Δx. Further division of this cross-sectional storage area by the storage depth, d' gives the equivalent width, $b_{storage}$, of the schematized rectangular cross-section. These relationships area:

$$V_{storage} = A^s_{storage} \quad d'$$

$$A_{storage} = \frac{V_{storage}}{\Delta x}$$

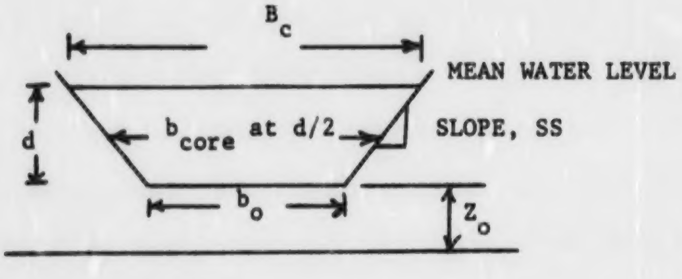

EMBAYMENT (A_s Storage)
STORAGE
CORE OF CONVEYANCE
LONGITUDINAL AXIS
Δx
PLAN VIEW

(a) PLAN


b_{total}
$b_{storage}$
b_{core}
MEAN WATER LEVEL
d'
STORAGE AREA
CORE AREA
d
Z'_b
Z_o
Datum

(b) CROSS-SECTIONAL REPRESENTATION IN TERMS OF CORE AND STORAGE AREAS

(a) and (b) SCHEMATIZATION - IRREGULAR CHANNELS WITH EMBAYMENTS OR STORAGE AREAS


B_c
MEAN WATER LEVEL
d
b_{core} at d/2
SLOPE, SS
b_o
Z_o

(c) SCHEMATIZATION - TRAPEZOIDAL CHANNEL

FIGURE 3.5 VARIOUS CHANNEL SCHEMATIZATIONS

$$b_{storage} = \frac{A_{storage}}{d'} = \frac{A^{s}_{storage}}{\Delta x}$$

The final relationship shows how the schematization process spreads out the surface area over the length between cross-sections, Δx.

The data required by the computer program for each section is:

1. the core width, b_{core} (BS)
2. the core depth, d (CORE)
3. the total width, $b_{total} = b_{core} + b_{storage}$ (B)
4. the storage depth, d' (DST)

It must be remembered that the depth is with respect to mean water level, which must be defined for this type of cross-section.

3.1.4b Schematization to Irregular Section, Variable Topwidth

This cross-section is the most general that can be defined, and is the one which best corresponds to cross-sections found in a natural environment. It can be constructed from bathymetric surveys, or from data given in a chart or map. The principal involved in this type of schematization is that the parameters used by the computer program for its calculations will be defined as functions of water surface elevation by the user. This means that the user must provide for each of several surface elevations the total top width (TW), the core width (CW), the core area (AREA), the wetter perimeter (WPERM), and the total cross-section area (TAREA). The surface elevation at which these values are to be supplied must be determined by the user. That is to say, the user must provide a table of incremental surface elevations and the corresponding parameters. The computer will interpolate within this table for the values of these parameters when the calculated surface elevation lies between the calculated values. Reference 10 describes a small computer program that has been developed to simplify preparation of this data starting from a table of offsets and depths taken-off a nautical chart. Figure 3.6 shows the irregular cross-section of varying top widths and how its parameters are related to the different surface elevations.

3.1.5 Simplified Cross-Sections

Simplified cross-sections as shown in Figure 3.3 are rectangular, trapezoidal and circular. These cross-sections are specified in terms of their basic dimensions. For the rectangular and trapezoidal cross-sections, the bottom width and bottom elevation are specified. For the trapezoidal cross-section the side slope and bottom elevation are specified, and for the circular cross-section the pipe radius and bottom elevation are specified. It should be mentioned that the circular cross-section option has not been tested and is available only with a constant radius pipe for each reach. The trapezoidal and rectangular cross-sections can be of different dimensions throughout a particular reach, or for a prismatic geometry a single cross-section can be specified. When a single cross-section is specified for the entire reach, a reach slope specification can be used to relate the prismatic geometry to the common datum.

3.2 Calculation of Hydraulics

This model's ability to accurately calculate the hydraulics is the primary ingredient for a successful calculation of water quality. This is especially true for tidal modeling wherein the correct calculations of the reversing flow enables a rational approach to the dispersion phenomena

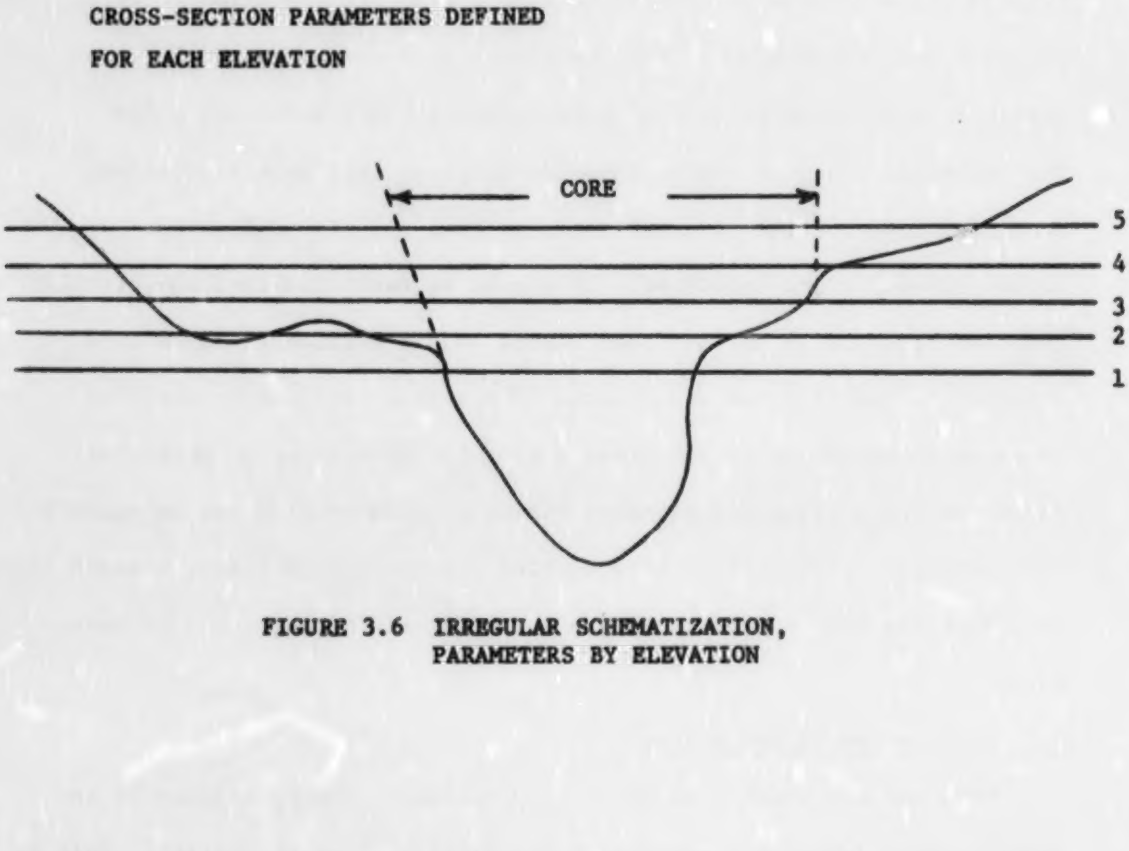

CROSS-SECTION PARAMETERS DEFINED
FOR EACH ELEVATION
CORE
5
4
3
2
1

FIGURE 3.6 IRREGULAR SCHEMATIZATION, PARAMETERS BY ELEVATION

including salinity intrusion effects, (Harleman and Thatcher 1974, Thatcher and Harleman 1972). Although it is possible to specify geometry, roughness, boundary and initial conditions and then proceed to predict the hydraulics, it is desirable to have some observed data for the purpose of verification or calibration.

3.2.1 Selection of Δt and Δx

The discretization requirements of the numerical solution to the hydraulic equations and to the water quality equations are distinct. This model employs interpolation as a means of allowing the user to specify distinct mesh spacings (Δx's) for the two calculations. It is also permissible for the user to specify a water quality Δt which is an integer multiple of the hydraulics Δt. These considerations lead to the specification of Δx's and Δt's for the hydraulics that are, or can be, independent of water quality criteria.

Within the computer program, the hydraulic time increment is calculated as:

$$\Delta t_H = \frac{\text{duration of time period in seconds}}{\text{number of hydraulic increments per period}}$$

The user supplies the duration of period and number of increments. For an estuary problem the time period is the tidal period. In the case of a river, the number of periods is set to one and the duration of the time period is the duration of the study or run.

The choice of Δt_H remains an art; however, Gunaratnum and Perkins (1970) have derived the following criterion for the time step in the hydraulic model:

$$\Delta t_H \leq 5.5 \frac{\Delta X_H}{v + c} \qquad (3.1)$$

where

$v = \frac{Q}{A}$

$c = \sqrt{g \frac{A}{B}}$

Q = discharge

A = cross-sectional area

g = acceleration of gravity

ΔX_H = hydraulic space increment

B = surface width

The factor of 5.5 is based on some rather stringent requirements and a factor of 11 has been used with reasonable results. The choice of Δt_H also depends on the choice of ΔX_H, for which Gunaratnum and Perkins have also given criteria. In actual practice, the choices of ΔX_H and Δt_H are usually dictated by practical considerations. Foremost among them is computer time, which will be minimized when ΔX_H and Δt_H are maximized for each reach.

The choice of Δx_H is specific to each reach in the network but is of constant value within each reach. As mentioned in Section 3.1.3, ΔX_H

should be at least as small as the closest spacing between user defined cross-sections, consequently the variation of reach geometry is an important consideration in the selection of ΔX_H. The numerical operation in the hydraulic model spans three mesh points; therefore, it is wise to have a minimum of three or four Δx's in each reach to arrive at a reasonable solution. This implies that short reaches should be avoided where possible. In highly irregular channels, it may be necessary to make a tradeoff between resolution of detail and computer time. In shallow rivers and estuaries, it may be possible to use a large Δt_H, however, care should be taken to see that there are enough meshpoints to describe the lateral inflows and boundary conditions accurately.

3.2.2 Boundary Conditions

For subcritical flow, three possible boundary conditions can be specified. They are:

(1) The Discharge Q.

(2) The surface elevation Z.

(3) A relationship between Z and Q.

As the M.I.T. Open Channel Network is applicable only to subcritical flow conditions (practical considerations), only one time history Z(t), Q(t) or Z vs. Q is required at each boundary. Typical boundary specifications would be a water surface elevation at the downstream boundary of a tidal estuary, a discharge boundary condition for upstream flood flows or releases from a dam, and a Z vs. Q rating curve for control structures such as weirs, gates and spillways. The concept of a control structure can be extended to the downstream boundary in long rivers in terms of a stage-routing condition. Henderson (1966, Chapter 9.8) shows that for flood routing a loop-rating curve applies, as shown in Figure 3.7.

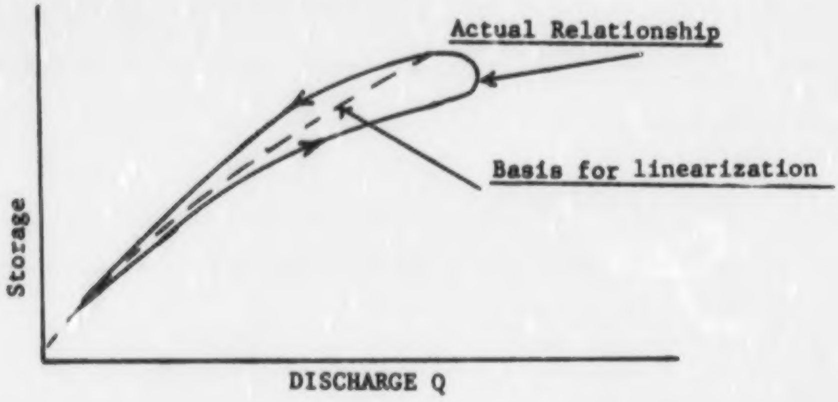


FIGURE 3.7 STAGE - DISCHARGE CURVE

For flood routing and for uniform flow in straight channels

$$Q = C_z A \sqrt{R(So - \frac{\partial h}{\partial x})} \qquad (3.2)$$

Equation 3.2 can be used to define the relationship of Figure 3.7. Gunaratnam and Perkins have used this as a boundary condition inasmuch as the relationship yields a rating curve. They expand Q in a Taylor series in time using the interrupted line of Figure 3.7 as a basis for the expansion. The Z vs. Q relationship derived in this manner has given good results in many cases.

Control Structures The model can simulate control structures within the network itself instead of only at the boundaries. In general it is advisable to divide up a large network into smaller ones, using control structures as the natural points of subdivision. (This results in large savings in computation costs as well as organizational convenience.) Such subdivisions would place control structures at boundaries, but this is not always possible, nor desirable.

The model permits the user to specify a boundary condition at the upstream side of the control structure. The upstream side of the control structure becomes a node in the Network Topology - a boundary node. The downstream side of the control structure is also a boundary node, distinct from the upstream node. The boundary condition applied at this downstream node will be the discharge calculated at the upstream node at the previous time step or, if discharge were the specified boundary condition, the specified discharge. Figure 3.8 shows a typical control structure network where the flow splits at node 2 into two branches. One branch (or reach) goes directly to node 5, whereas the other passes through a control structure. Node 3 is the upstream node of the control structure, node 4 the downstream node. Confluence occurs at node 5.

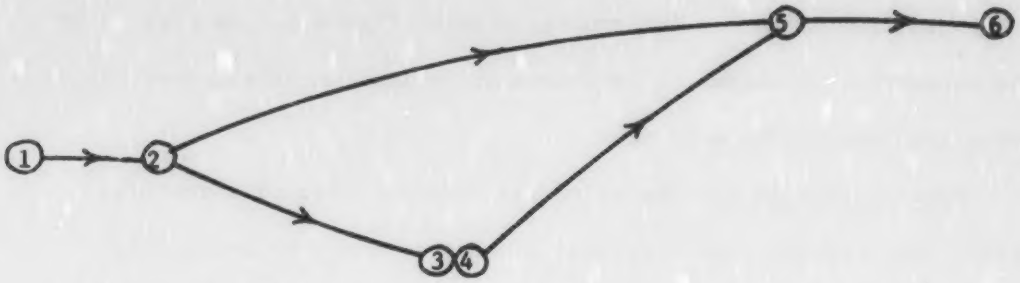


FIGURE 3.8 TYPICAL CONTROL STRUCTURE AT NODES 3 and 4

Rapids Rapids represent a section of river where flow becomes critical. Although this model is valid for such cases, it becomes impractical as the discretization increment, Δx, for critical flow would be very small in order to satisfy convergence criteria. Rapids are similar to control structures in that they can be studied in terms of a rating curve. If such a curve can be established by field measurements then the rapids can be treated as a control structure. If obtaining such a curve is impractical, two other possibilities exist. One is to assume a rating curve, such as:

$$q = 3.33 H^{3/2}$$

where q is the discharge per unit width and H is the depth at the head of the rapids. The other possibility is to treat the upstream boundary of the equivalent control structure as a stage-routing type boundary.

Ice Cover The effect of ice cover can be introduced into the numerical solution to the governing equations. This is accomplished through relating both the hyraulic radius R_h and the friction factor (Manning's n or Chezy coefficient C) to the presence of an ice cover on the surface of the reach.

Specifying "Ice Cover" effectively adds the surface width to the wetted perimeter, thereby decreasing the hydraulic radius which is defined as the cross-sectional area A, divided by the wetter perimeter WP.

In applying the ice cover option the user must give careful consideration to the resistance coefficient which he selects for the ice covered reach. Peter Larsen (1973 and 1969), has made significant contributions in this field and the user is urged to consult his work as a means of determining a composite Manning's n which includes ice effects.

3.2.3 Initial Conditions

Even for "steady-state" applications it is necessary to supply initial conditions. This is because the model is a transient model and the steady-state mode is defined in terms of a transient solution that converges to a steady condition in the case of rivers or to a repeating tidal condition in what is called "quasi-steady state" in the case of estuaries.

The initial conditions of water surface elevation Z and discharge Q, should be the best estimate possible. Two means of specifying these conditions are available. One is to specify them as part of the geometric definition of each reach. The other is to use values calculated by previous applications of the model.

3.2.4 Roughness Parameter Calibration and Verification

Assuming that data exists for the waterway being modeled, such data can be used to calibrate the model. The primary variable for calibration is the roughness parameter as expressed by Manning's n. The user specifies 'n' for each reach or for each user defined cross-section. Although experimentally determined relationships for open channel flow (Chow 1959) can be used as a guideline, the Manning's n values should be adjusted to make the model's calculations fit the observed data.

For estuaries, data on tidal range and phase can be used to insure that the model correctly represents the advective characteristics. This calibration process is accomplished by varying the channel roughness (Manning's n) so as to achieve the best fit with data. Often the data is presented in terms of local tidal range and phase lags for a particular tidal range at the ocean, or downstream boundary. The tidal runs are made by prescribing average tributary inflows and holding these constant for each tidal cycle of calculation. The time-varying surface elevation at the ocean is repeated for each tidal cycle. Such a repetition of boundary conditions defines a quasi-steady state condtion. Initial conditions of surface elevation and discharge can be approximated (or set equal to zero) and a reasonable approximation of the longitudinal salinity distribution can be used for an initial condition on salinity. The numerical model is then run and it has been found that about 5 to 8 tidal periods of calculation will result in tidal elevations and discharges which are essentially the same from one period to the next. This procedure can be applied for different variations in channel roughness until the resulting convergent surface elevations give a satisfactory verification of the tidal data. The study can then be continued using this distribution of channel roughness. It is noted that the tidal hydraulics are not very sensitive to small changes in the salinity distribution and this is why the above procedure can be successfully executed using only an approximate salinity distribution.

When the calibrated model is applied to a different flow condition for which data exists, the comparison of model results with data constitutes a verification of the model. Each verification will have to be considered in terms of the accuracy of the data itself as well as the degree of precision with which the geometry has been modeled. For estuarine work it must be kept in mind that the mean range and phase lags given in Tide Tables do not specify the average tributary inflows. The representation of storage volumes can also affect the calibration/verification process. Care must be taken to account for all storage areas in order to have a more accurate model.

3.3 Calculation of Water Quality

3.3.1 Lateral Inflows and Injection Points

The model provides a general technique for specifying lateral inflows along the longitudinal axis of each reach. This technique provides the necessary information in terms of both hydraulic and water quality inflow. The specification is that of a distributed time-varying or constant input. Obvious applications arise from cases of overbank flow and certain tributary inflows, however other cases such as benthic demand can also be specified.

Although a point source discharge can be specified using the "Lateral Inflow" specification of zero width, a special "Injection" loading option is available which eliminates the necessity to specify the hydraulic input. This "Injection" specification should be used only when the injection loading has no hydraulic significance.

3.3.2 Selection of Δx and Δt for Water Quality Calculations

As mentioned in Section 3.2.1, the choice of Δx and Δt for the water quality solution can be distinct from the Δx, Δt used for the hydraulic solution. This is possible through interpolation from one spatial discretization system to the other, and through permitting the Δt_{WQ} to be specified as an integer multiple of the Δt_H. Detailed criteria for the choice of Δx and Δt have been developed by Dailey and Harleman (1972).

Instead of repeating the detailed considerations for discretization given by Dailey and Harleman the following guidelines are presented to give the user an initial set of values. The actual application will have its own requirements in terms of precision and its geometry will play an important part in the trade-off between convergence to a smooth solution and economies of computation. The ability of the water quality model to provide for a varying Δx is in itself economical of computation. The user is reminded that he can make use of this feature by refining his computational mesh in areas of steep concentration gradients such as those encountered at an outfall or at a confluence of two reaches of distinct water qualities.

In choosing Δx the wave number, ω, corresponding to an assumed concentration distribution composed of harmonics is the parameter through which the user can specify the amount of oscillation which he will tolerate in his solution. Figure 3.9 shows a nondimensional plot of wave number versus distance from an injection point, or versus distance from the head of the reach in the case of a confluence of reaches of different quality. By selecting a distance x, estimating a value of velocity U,

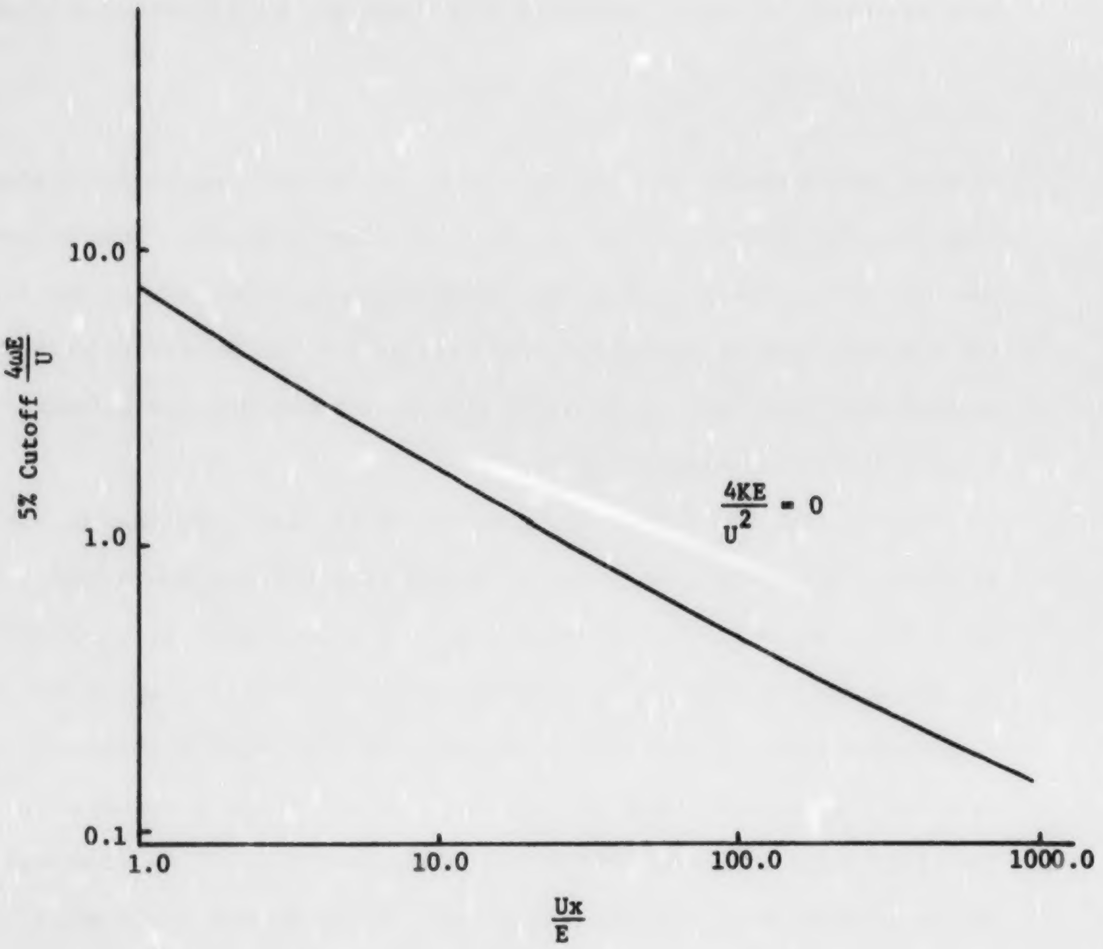


FIGURE 3.9 5% CUTOFF WITH ZERO DECAY

and dispersion coefficient E (for example by equation 3.4), Figure 3.9 is used to get a value ω_{max}. With this value of ω_{max} one can check the required spacing Δx using the formula $\Delta x \leq \frac{1}{\omega_{max}}$. Once x is found by this criteria, Δt can be estimated by the use of the following two formulae:

$$\Delta t \leq \frac{\Delta x}{U} \quad , \qquad \Delta t \leq \frac{(\Delta x)^2}{2E} \qquad (3.3)$$

It must be remembered that the initial x used corresponds to the distance away from the injection point or source of steep gradient. This is where the user first wishes to have the concentration calculated. As one gets further away from this critical point Figure 3.9 can be used to estimate greater mesh spacings. In order to clarify further this approximate procedure a simple example follows.

Assume that the dispersion, E equals 50 ft.^{2}/sec. and that U, the velocity, equals 2 ft./sec. Let us assume that the user would like to use a Δx of about 500 ft. in the vicinity of an outfall. He would then calculate the corresponding ω using Figure 3.9 as .012 by which the required Δx would be less than or equal to 83 ft. At this point the user could proceed to calculate the required Δt (42 sec.) and abandon his wish to use a spacing of 500 ft. in the vicinity of the discharge. The recalculation of the required Δx 1000 ft. downstream would still only permit a Δx of 125 ft. In such a case it would be advisable to try several Δx's in order to verify from the model results the effect of this particular convergent parameter. Inasmuch as different uses of the model will require different degrees of accuracy the use of the 5 percent cutoff shown in Figure 3.9 as an absolute criterion is obviously arbitrary. Consequently the user is advised to use these methods as guidelines only.

Some typical values used in large estuaries are 20 to 50 time steps per tidal period and Δx_{WQ} from 500 to 2000 feet. Each application should be treated uniquely as indicated above.

3.3.3 Initial and Boundary Conditions

Initial Conditions

An initial condition of water quality concentration is required for the solution of the partial differential equations. The program has been written so as to facilitate a direct specification of initial condition by allowing the user to specify initial concentrations at as few locations as he finds necessary for each reach, the program performing interpolations to all the defined water quality mesh locations. If the water quality initial condition is not known and a steady-state or quasi steady-state solution is desired, the best estimate of the solution should be used as an initial condition. The computer solution will begin with this estimate and converge to the desired solution. It is recommended to make use of the plotting program as a means for measuring this convergence.

Boundary Conditions

The model provides three possible boundary conditions and a special ocean boundary procedure. The three basic specifications are concentration, dispersive flux and total flux. Practical considerations will govern the selection of boundary conditions, however numerical stability imposes a restriction on the use of the dispersive flux condition. The dispersive flux condition should not be specified at boundaries where the flow is towards the other end of the reach. Typically, this would be at an upstream boundary of a river system. If the concentration is not known at such a boundary the total flux condition should be specified by evaluating the inflow times the inflow concentration. In the case of an ocean boundary, a special feature is included to permit the user to specify a concentration during part of the flooding flow only. In this way the concentration calculated at the end of the ebbing flow (at low water slack) will serve as the beginning concentration of an exponential relationship between the user-specified ocean concentration and the low water slack concentration. Figure 3.10 illustrates how the downstream boundary concentration is divided into two types: an outflowing time period wherein the boundary formulation is specified internally by the computer using a dispersive flux condition, and an incoming time period, during which the computer program exponentially interpolates between the low water slack concentration and the user specified ocean concentration using a time constant supplied by the user. The formula for this flooding flow concentration boundary condition is as follows:

$$\begin{array}{lll} C & = \text{(internally calculated using dispersive flux} & \begin{array}{l}\text{Ebbing Flow} \\ Q \geq 0\end{array} \\ & = C_o + (C_o - C_{LWS})e^{-k(t-t_{LWS})} & \begin{array}{l}\text{Flooding Flow} \\ Q < 0\end{array} \end{array}$$

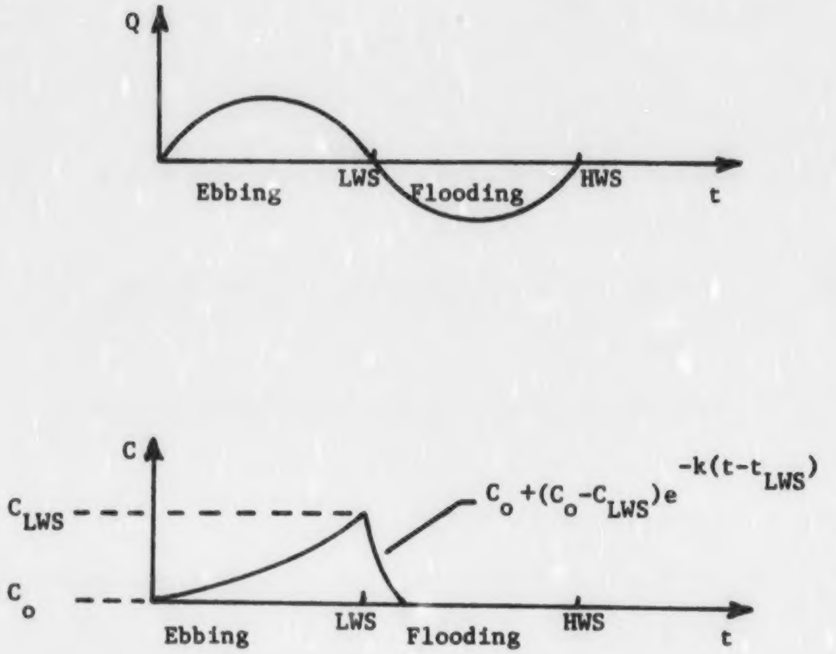

Q
Ebbing
LWS
Flooding
HWS
t
C
C_{LWS}
C_o
$C_o + (C_o - C_{LWS})e^{-k(t-t_{LWS})}$
Ebbing
LWS
Flooding
HWS
t

FIGURE 3.10 OCEAN BOUNDARY WATER QUALITY CONDITIONS

3.3.4 Dispersion Relationships

The longitudinal dispersion coefficient is determined by summing the effects of density induced circulation due to salinity gradients and the mixing due to the actual non-uniformity in the velocity profile. Thatcher and Harleman (1972) have verified a hypothesized dispersion coefficient which is expressed by:

$$E(x,t) = K \left|\frac{\partial \overset{\circ}{s}_{o}}{\partial x}\right| + m\, E_T \qquad (3.4)$$

where

$E(x,t)$ = temporally and spatially varying dispersion coefficient, ft^2/sec

K = estuary dispersion parameter = $0.002\, u_o L (\mathbb{E}_D)^{-1/4}$, ft^2/sec

u_o = maximum velocity at the ocean boundary, ft/sec

L = length of estuary to head of tide

$\mathbb{E}_D$ = estuary number = $P_t\, \mathbb{F}_o{}^2/Q_f T$

P_t = tidal prism (volume of water entering the estuary on flood tide) = $\frac{2}{\pi} u_o\, A_o\, \frac{T}{2}$, ft^3

$\mathbb{F}_o$ = densimetric Froude number =

$$\frac{u_o}{\sqrt{g\left(\frac{\Delta\rho_o}{\rho}\right) h}}$$

g = acceleration due to gravity, ft/sec^2

$\frac{\Delta\rho_o}{\rho}$ = salt-water; fresh-water density difference = $\frac{\rho_o - \rho}{\rho}$

h = mean depth of estuary, ft

Q_f = rate of fresh water inflow, ft^3/sec

T = length of tidal period, sec

$\overset{\circ}{s} = \frac{s}{s_o}$ where $s = s(x,t)$ = the temporal and spatial distribution of salinity, ppm

s_o = ocean salinity, ppm

$\overset{\circ}{x} = \frac{x}{L}$

x = distance from the ocean boundary, ft

m = a multiplying factor for bends and channel irregularities

E_t = Taylor's dispersion coefficient = $77\ u\ n\ R_h^{5/6}$, ft^2/sec

$u = u(x,t)$ = tidal velocity, ft/sec

n = Manning's friction coefficient

R_h = hydraulic radius, ft

3.3.5 Salinity Modeling

Salinity distribution is handled as a conservative substance. The source of salinity in an estuary netwrok is the ocean which is usually the boundary of the estuary. Salinity is also coupled to the hydrodynamic equations through the salinity-density relationship.

The one-dimensional mass conservation equation for this parameter is:

$$\frac{\partial}{\partial t}(AS) + \frac{\partial}{\partial x}(QS) = \frac{\partial}{\partial x}\left(AE\ \frac{\partial s}{\partial x}\right) + \frac{Ar_e}{\gamma} \qquad (3.5)$$

where S is the concentration of salinity in mg/ℓ and all other terms have been defined previously.

3.3.6 Temperature Modeling

The mathematical model for transient temperature distribution in unsteady flows has been developed in Harleman *et al*. (1973). The inputs to the model are: (1) the ambient atmospheric temperature in °F, (2) the percent relative humidity, (3) the wind velocity at 2 meters above the water surface in mph, (4) atmospheric pressure in mm Hg, (5) net solar flux and net atmospheric flux at the surface of the water in BTU/ft^2/day, and (6) waste heat discharged into the ecosystem in BTU/ft/day. In cases where the temporal and spatial variation of temperature is not desired, constant water temperatures must be specified because all transformation kinetics are temperature dependent.

The one-dimensional mass conservation equation for this parameter is

$$\frac{\partial}{\partial t}(AT) + \frac{\partial}{\partial x}(QT) = \frac{\partial}{\partial x}\left(AE\,\frac{\partial T}{\partial x}\right) + \frac{b(x)\phi_n(t)}{\gamma c} + \frac{WHD}{\gamma c} + \frac{THD}{\gamma c} \qquad (3.6)$$

where:

T = cross-section averaged temperature in °F

$b(x)$ = top width of channel in ft

$\phi_n(t)$ = net heat flux into water surface in BTU/ft^2/day

WHD = waste heat discharge in BTU/ft/day

γ = specific weight of water in lb/ft^3

c = specific heat of water in BTU/lb/°F

THD = tributary heat discharge in BTU/ft/day

3.3.7 Carbonaceous B.O.D. Modeling

Carbonaceous B.O.D. is handled as a first order decaying substance in the classical manner. The inputs to the model are the upstream and downstream boundary fluxes and the discharges from municipalities, industries, and storm runoff. CBOD is coupled in a feed-forward manner to the dissolved oxygen (DO) equation.

The one-dimensional mass conservation equation for CBOD is:

$$\frac{\partial}{\partial t} (AC) + \frac{\partial}{\partial x} (QC) = \frac{\partial}{\partial x} [AE \frac{\partial C}{\partial x}] - A\, K_{BOD}\, C + \frac{Ar_e}{\gamma} \qquad (3.7)$$

where

C = concentration of CBOD in mg/ℓ

K_{BOD} = rate of CBOD decay in 1/day

The reaction rate is assumed to be temperature dependent only according to the form below:

$$K_{BOD}(T) = K_{BOD}(20°C)\ \theta^{(T-20)} \qquad (3.8)$$

where T is the temperature in degrees centigrade. The values of $K_{BOD}(20°C)$ and θ may be stipulated by the user or the program default values described in Section 5.4 may be used.

3.3.8 Nitrogen Cycle Modeling

The nitrogen cycle structure is presented in Figure 3.11. The model is developed for aerobic estuarine ecosystems and includes seven storage variables and twelve transformations of nitrogen between those variables. The storage variables include: (1) N_1, Ammonia-N, (2) N_2, Nitrite-N, (3) N_3, Nitrate-N, (4) N_4, Phytoplankton-N, (5) N_5, Zooplankton-N, (6) N_6, Particulate Organic-N, (7) N_7, Dissolved Organic-N. The transformations include: (1) nitrification (2) uptake of inorganic nitrogen by phytoplankton (3) grazing of herbivores (4) ammonia regeneration in living cells (5) release of organic matter from living cells (6) natural death of living organisms and (7) ammonification of organic nitrogen.

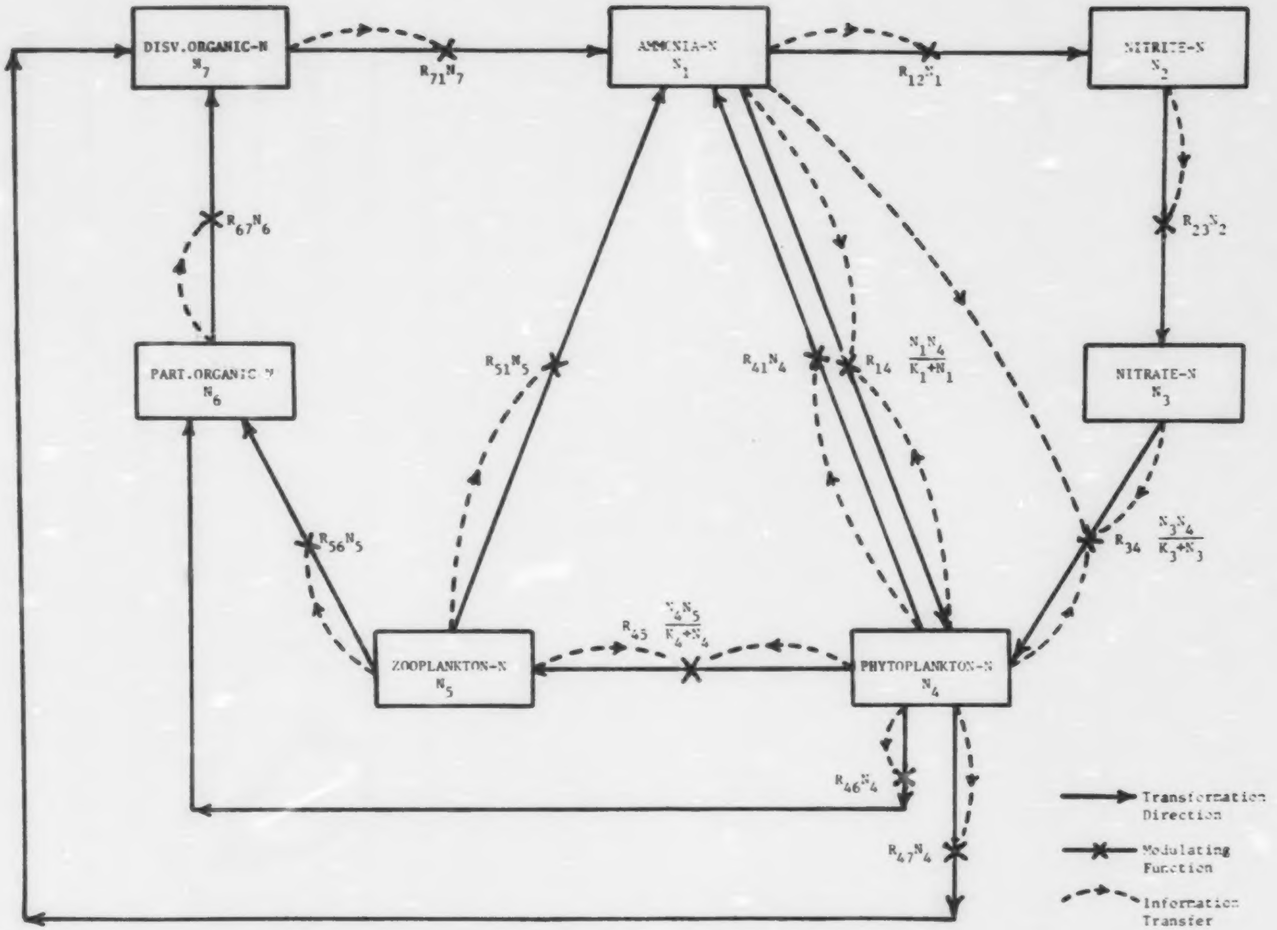
In Figure 3.11, the boxes represent the various storage variables of the element nitrogen. The solid lines show transformation pathways. The cross marks (x) on the solid lines represent functions which determine the speed of the transformations. The functions are dependent on the storage variables and external environmental inputs (e.g., temperature and light). Dashed lines indicate the transfer of information from storage variables to the rate determining functions.

The conservation of mass equations for the nitrogen cycle variables are:

$$\frac{\partial}{\partial t}(AN_1) + \frac{\partial}{\partial x}(QN_1) = \frac{\partial}{\partial x}(AE\,\frac{\partial N_1}{\partial x}) + AR_{41}N_4 + AR_{51}N_5 + AR_{71}N_7 - AR_{14}\,\frac{N_1N_4}{K_1 + N_1} + AR_{12}N_1 + \frac{A\,r_{e_1}}{\gamma} \tag{3.9}$$

$$\frac{\partial}{\partial t}(AN_2) + \frac{\partial}{\partial x}(QN_2) = \frac{\partial}{\partial x}(AE\,\frac{\partial N_2}{\partial x}) + AR_{12}N_1 - AR_{23}N_2 + \frac{A\,r_{e_2}}{\gamma} \tag{3.10}$$

$$\frac{\partial}{\partial t}(AN_3) + \frac{\partial}{\partial x}(QN_3) = \frac{\partial}{\partial x}(AE\,\frac{\partial N_3}{\partial x}) + AR_{23}N_2 - AR_{34}\,\frac{N_3N_4}{K_3 + N_3} + \frac{A\,r_{e_3}}{\gamma} \tag{3.11}$$



DISV.ORGANIC-N
N_7
AMMONIA-N
N_1
NITRITE-N
N_2
NITRATE-N
N_3
PHYTOPLANKTON-N
N_4
ZOOPLANKTON-N
N_5
PART.ORGANIC-N
N_6
$R_{71}N_7$
$R_{12}N_1$
$R_{23}N_2$
R_{34} $\frac{N_3N_4}{K_3+N_3}$
R_{14} $\frac{N_1N_4}{K_1+N_1}$
$R_{41}N_4$
$R_{51}N_5$
R_{45} $\frac{N_4N_5}{K_4+N_4}$
$R_{56}N_5$
$R_{67}N_6$
$R_{46}N_4$
$R_{47}N_4$
Transformation Direction
Modulating Function
Information Transfer

FIGURE 3.11 NITROGEN - CYCLE STRUCTURE IN AEROBIC AQUATIC ECOSYSTEMS

$$\frac{\partial}{\partial t}(AN_4) + \frac{\partial}{\partial x}(QN_4) = \frac{\partial}{\partial x}(AE\,\frac{\partial N_4}{\partial x}) + AR_{14}\,\frac{N_1N_4}{K_1 + N_1} + AR_{34}\,\frac{N_3N_4}{K_3 + N_3} - AR_{45}\frac{N_4N_5}{K_4 + N_4} - A(R_{41} + R_{46} + R_{47})N_4 + \frac{A\ r_{e_4}}{\gamma} \tag{3.12}$$

$$\frac{\partial}{\partial t}(AN_5) + \frac{\partial}{\partial x}(QN_5) = \frac{\partial}{\partial x}(AE\,\frac{\partial N_5}{\partial x}) + AR_{45}\,\frac{N_4N_5}{K_4 + N_4} - A(R_{56} + R_{51})N_5 + \frac{A\ r_{e_5}}{\gamma} \tag{3.13}$$

$$\frac{\partial}{\partial t}(AN_6) + \frac{\partial}{\partial x}(QN_6) = \frac{\partial}{\partial x}(AE\,\frac{\partial N_6}{\partial x}) + AR_{46}N_4 + AR_{56}N_5 - AR_{67}N_6 + \frac{A\ r_{e_6}}{\gamma} \tag{3.14}$$

$$\frac{\partial}{\partial t}(AN_7) + \frac{\partial}{\partial x}(QN_7) = \frac{\partial}{\partial x}(AE\,\frac{\partial N_7}{\partial x}) + AR_{47}N_4 + AR_{67}N_6 - AR_{71}N_7 + \frac{A\ r_{e_7}}{\gamma} \tag{3.15}$$

The description of the twelve transformation processes considered in the nitrogen cycle model as shown in Figure 3.11 are presented here. Table 3.1 shows the matrix of all the assumed transformations in the model. The model structure has been developed so that improvements and modifications of rate determining expressions can be made. For a detailed discussion of these transformations, the user is referred to Najarian and Harleman (1975), pages 107 to 148. A short description of the functional dependencies of each transformation is presented below.

TABLE 3.1 TRANSFORMATION MATRIX FOR AN AEROBIC ECOSYSTEM

from \ to	N_1 NH_3-N	N_2 NO_2-N	N_3 NO_3-N	N_4 PHYTO-N	N_5 ZOOPL-N	N_6 DON	N_7 DON
N_1 NH_3-N		TR_{12}		TR_{14}			
N_2 NO_2-N			TR_{23}				
N_3 NO_3-N				TR_{34}			
N_4 PHYTO-N	TR_{41}				TR_{45}	TR_{46}	TR_{47}
N_5 ZOOPL-N	TR_{51}					TR_{56}	
N_6 DON							TR_{67}
N_7 DON	TR_{71}						

$$h_1(T) = \left(\frac{T}{T_{opt}}\right)^n \exp\left(1 - \left(\frac{T}{T_{opt}}\right)^{n'}\right) \qquad \text{for } 0 < T < T_{opt} \qquad (3.21)$$

$$h_2(T) = 1 - \left\{\frac{T - T_{opt}}{T_{max} - T_{opt}}\right\}^m \qquad \text{for } T_{opt} < T < T_{max} \qquad (3.22)$$

T = temperature of water, °C

T_{opt} = optimum temperature for uptake, °C

T_{max} = maximum temperature for uptake, °C

n = a constant = 2.5

m = a constant = 2.0

This function is shown graphically in Figure 3.12.

Uptake of Nitrate-N by Phytoplankton, TR_{34}

This process is also characterized by functions for light and dark hours.

$$R_{34}(I,H,k_e,T) = R \cdot g(I,H,k_e) \cdot h_{1,2}(T) \qquad \text{in light} \qquad (3.23)$$

$$R_{34}(T) = R \cdot h_{1,2}(T) \qquad \text{in dark} \qquad (3.24)$$

where

$$R = (R_{MIN})_{34} + \left(1 - \frac{N_1}{N_{1_c}}\right)(R_{MAX_{34}} - R_{MIN_{34}}) \qquad \text{for } N_1 < N_{1_c} \qquad (3.25)$$

$(R_{MIN})_{34}$ = minimum nitrate uptake rate by phytoplankton, day^{-1}

$(R_{MAX})_{34}$ = maximum nitrate uptake rate by phytoplankton, day^{-1}

N_{1_c} = concentration of NH_3-N above which NO_3-N uptake is a constant

This is shown graphically in Figure 3.13.

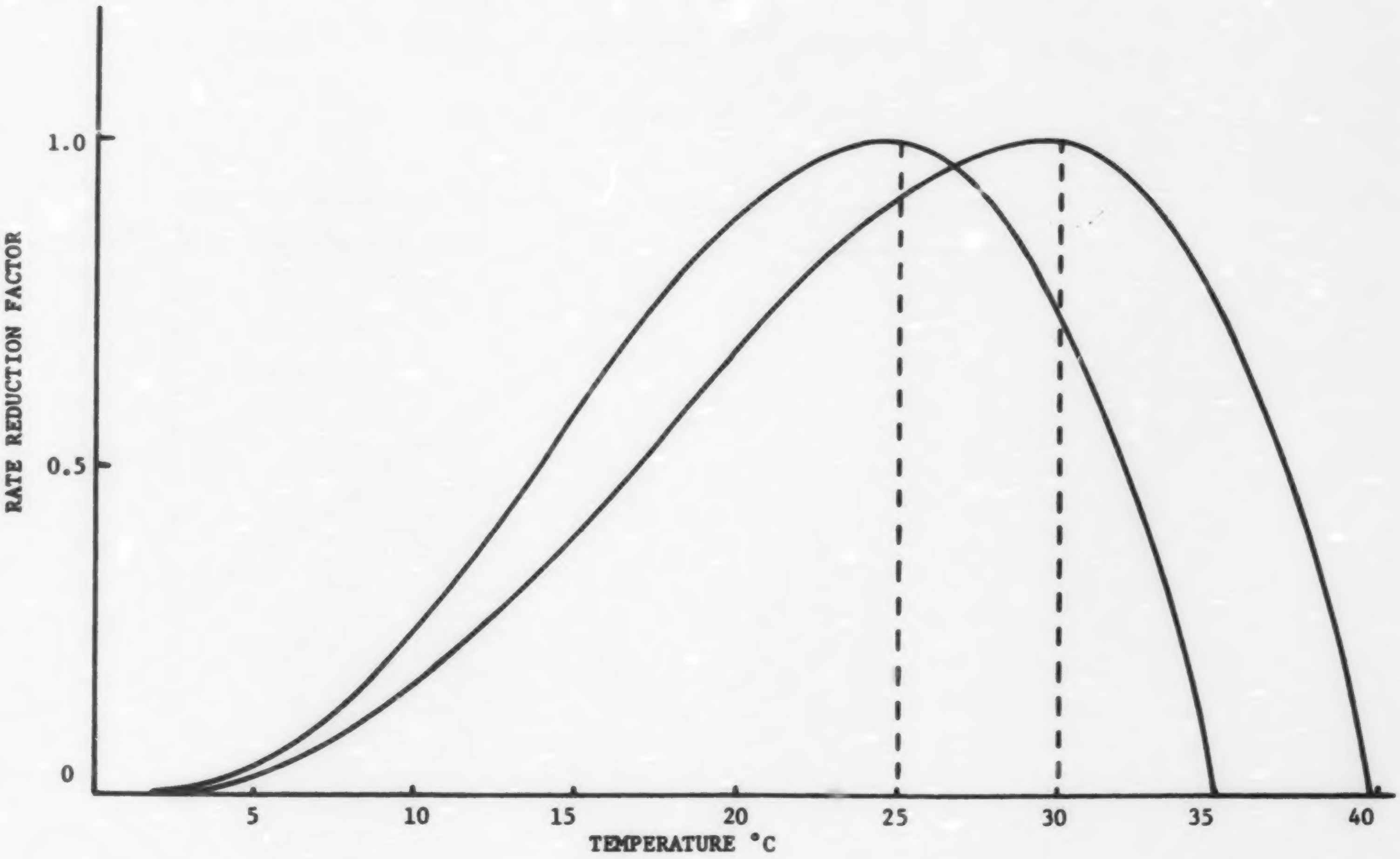


FIGURE 3.12 UPTAKE RATE REDUCTION WITH TEMPERATURE

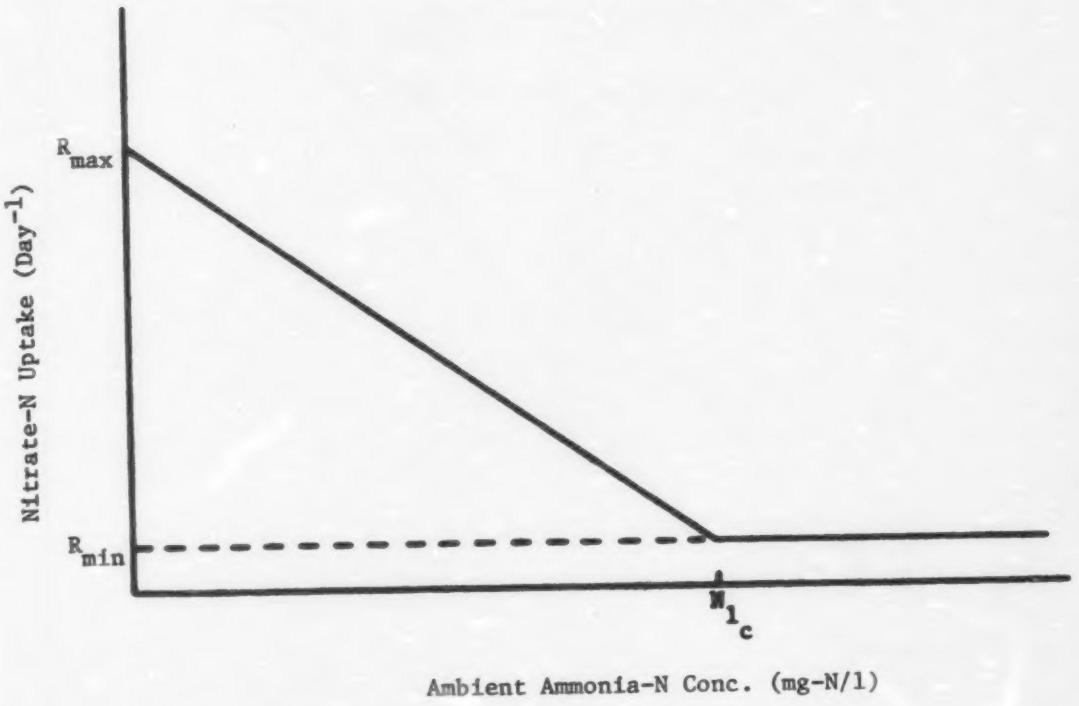


FIGURE 3.13 NITRATE-N UPTAKE VERSUS AMBIENT AMMONIA-N CONCENTRATION

Grazing of Zooplankton, TR_{45}

This process is characterized by functions for light and dark hours.

$$R_{45}(T) = (R_{MIN})_{45} \cdot h_{1,2}(T) \quad \text{in light} \qquad (3.26)$$

$$R_{45}(T,t) = (R_{MAX})_{45} \cdot h_{1,2}(T) \cdot z(t) \quad \text{in dark} \qquad (3.27)$$

where:

$$z(t) = \begin{cases} \sin\left[\frac{\pi}{12}(t - 18)\right] & \text{for } 18 \leq t \leq 24 \\ \sin\left[\frac{\pi}{12}(t + 6)\right] & \text{for } 0 \leq t \leq 6 \end{cases}$$

t = time of the night in hours (real time)

$(R_{MIN})_{45}$ = minimum zooplankton grazing rate, day^{-1}

$(R_{MAX})_{45}$ = maximum zooplankton grazing rate, day^{-1}

For the remaining nitrogen cycle transformations (listed below), the reaction rate is assumed to be temperature dependent only according to the form:

$$R(T) = R(20°C)\ \theta^{(T-20)}$$

where T = temperature in degrees centigrade. This applies to the following transformations:

Ammonia Regeneration by Phytoplankton, TR_{41}

Ammonia Regeneration by Zooplankton, TR_{51}

Release of Particulate Organic Nitrogen by Phytoplankton, TR_{46}

Release of Particulate Organic Nitrogen by Zooplankton, TR_{56}

Release of Dissolved Organic Nitrogen by Phytoplankton, TR_{47}

Hydrolysis of Particulate Organic Nitrogen to Dissolved Organic Nitrogen, TR_{67}

Hydrolysis of Dissolved Organic Nitrogen to Ammonia, TR_{71}

Default values for all of the above nitrogen cycle coefficients are given in the program. The user may override these and stipulate values of his choice as described in Section 5.4.

3.3.9 Dissolved Oxygen Modeling

The computation of the temporal and spatial distribution of dissolved oxygen is coupled to CBOD and the nitrogen cycle. A limited number of sources and sinks are considered. The sinks of DO are the oxidiation of C-BOD, NH_3-N and NO_3-N. The sources of DO are atmospheric reaeration at the water surface, and DO contained in waste discharges and lateral inflows.

The conservation of mass equation is written in terms of dissolved oxygen deficit (DOD) as below.

$$\frac{\partial}{\partial t}(AD) + \frac{\partial}{\partial x}(QD) = \frac{\partial}{\partial x}(AE\,\frac{\partial D}{\partial x}) + A\,K_{BOD}C + 3.43\;AR_{12}N_1 + 1.14\;AR_{23}N_2 - K_{re}AD - \frac{A\;re}{\gamma} \qquad (3.29)$$

where:

D = dissolved oxygen deficit (DOD) in mg/ℓ

K_{re} = rate of reaeration in 1/day

In the above equation, the only reaction rate which has not been discussed is the reaeration coefficient, K_{re}. This rate is expressed as a function of temperature, channel velocity, and geometry (i.e., total top-width, cross-sectional area, and depth).

$$K_{re} = 10.86(1.016)^{(T-20)} \frac{V^{0.6}}{H^{1.4}} H \frac{\text{Total Top Width}}{\text{Total Cross-Sectional Area}}$$

where

T = temperature, °C

V = velocity, ft/sec

H = depth, ft

Topwidth is in feet

Cross-sectional area is in ft^2

The values of 10.86 and 1.016 are the default values used in the program for these coefficients. The user may stipulate his own values as described in Section 5.4.

3.3.10 Fecal Coliform Modeling

Fecal coliform modeling is handled in the same manner as CBOD. Decay is a first order process and the inputs to the model are boundary fluxes, direct point discharges, and lateral inflows.

The one-dimensional mass conservation equation is:

$$\frac{\partial}{\partial t}(AF) + \frac{\partial}{\partial x}(QF) = \frac{\partial}{\partial x}\left[AE \frac{\partial F}{\partial x}\right] - A\, K_{FCOL}\, F + \frac{A_{re}}{\gamma} \qquad (3.31)$$

where:

F = concentration of fecal coliform

K_{FCOL} = rate of fecal coliform decay in 1/day

The reaction rate is temperature dependent and of the form:

$$K_{FCOL}(T) = K_{FCOL}(20°C)\ \theta^{(T-20)} \qquad (3.32)$$

where T is the temperature in degrees centigrade. The values $K_{FCOL}(20°C)$ and θ may also be stipulated by the user or the program default values described in Section 5.4 may be used as for the case of CBOD.

IV. STRUCTURE OF THE COMPUTER PROGRAM

The general structure of the computer program is illustrated in Figure 4.1. It is essentially a time-step procedure with the option of calculating either the hydraulics, the water quality concentrations or both. When only water quality is selected the hydraulics must be specified. The river or non-tidal case is handled as a single time period.

For steady-state hydraulics a convergence criteria is provided as well as a maximum number of tidal cycles should the specified criteria not be obtained. Steady-state water quality calculations are only steady-state with respect to hydraulics. The water quality concentrations are, in fact, transient and a real steady-state solution must be obtained through running the program until satisfactory convergence is obtained.

A more detailed flow chart is shown in Figure 4.2. In this figure programming sections are identified by the FORTRAN subroutine name. At this level of detail some familiarization with the program itself is assumed.

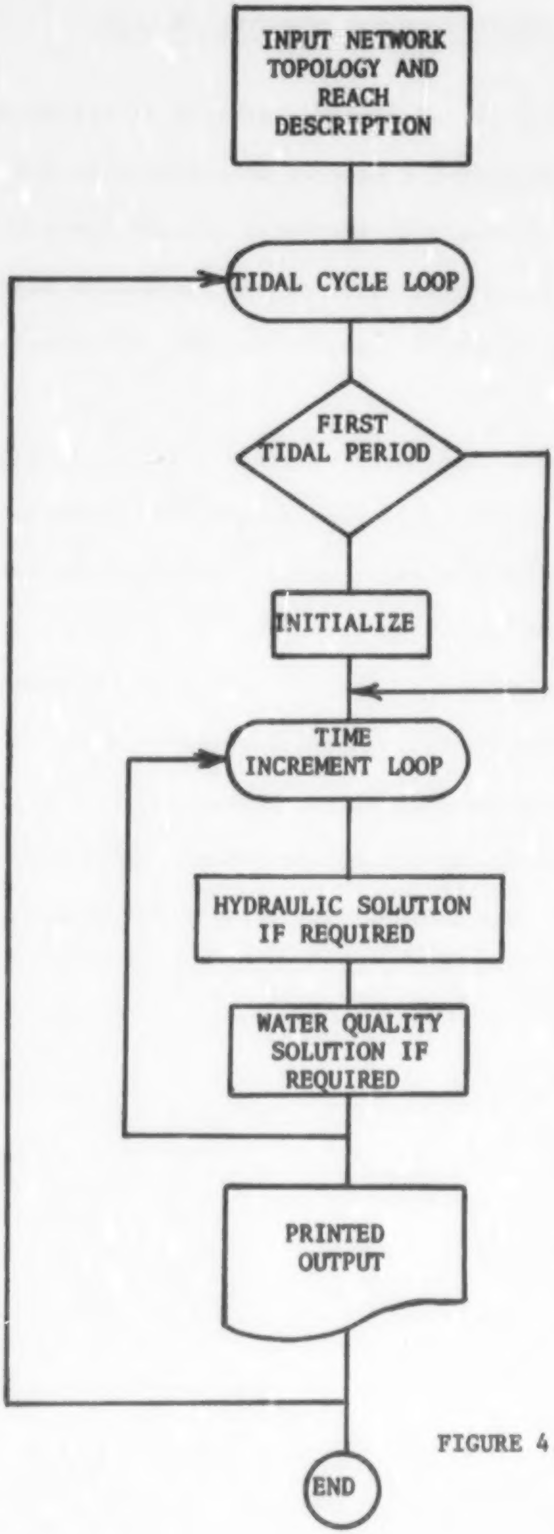

INPUT NETWORK TOPOLOGY AND REACH DESCRIPTION
TIDAL CYCLE LOOP
FIRST TIDAL PERIOD
INITIALIZE
TIME INCREMENT LOOP
HYDRAULIC SOLUTION IF REQUIRED
WATER QUALITY SOLUTION IF REQUIRED
PRINTED OUTPUT
END

FIGURE 4.1 BASIC PROGRAM FLOW CHART

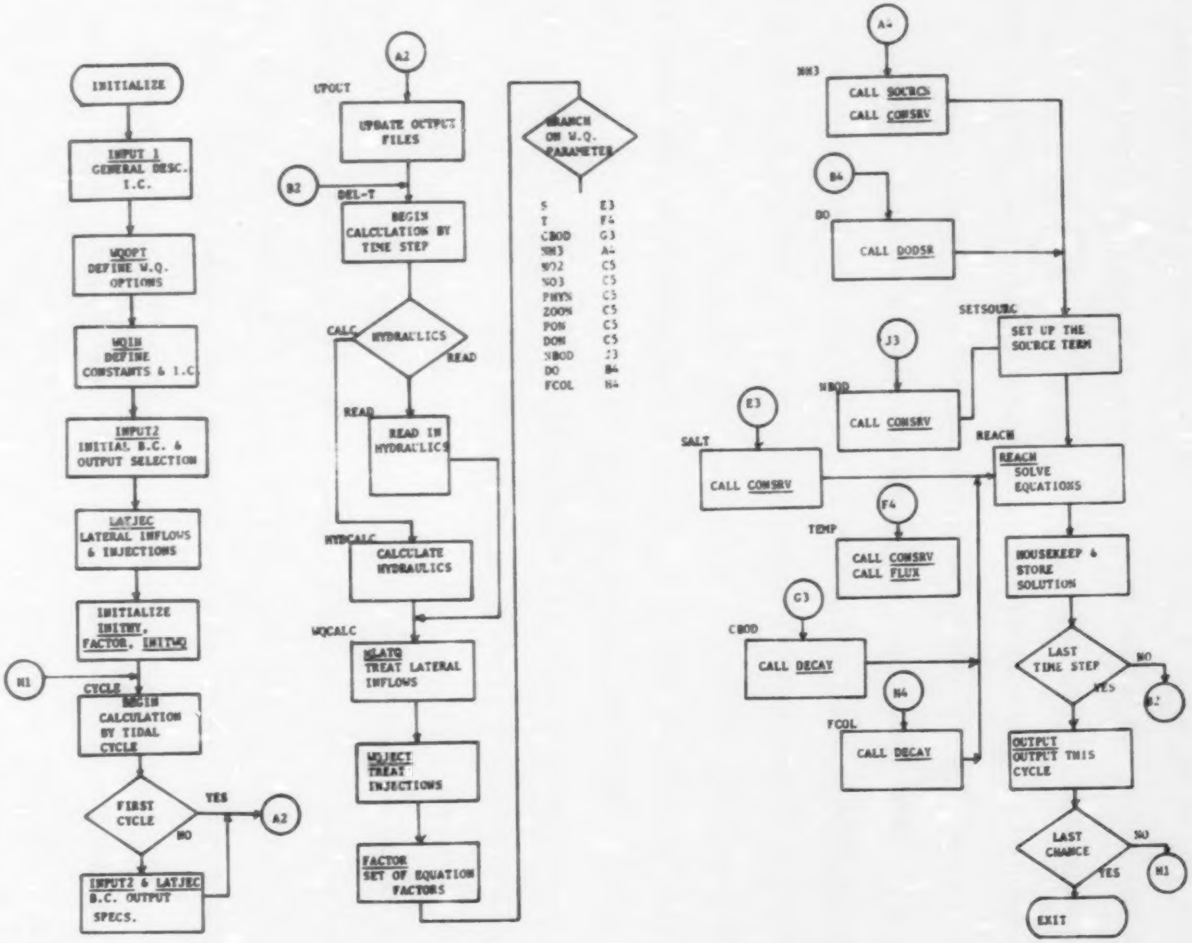

INITIALIZE
INPUT 1 GENERAL DESC. I.C.
WQOPT DEFINE W.Q. OPTIONS
WQIN DEFINE CONSTANTS & I.C.
INPUT2 INITIAL B.C. & OUTPUT SELECTION
LATJEC LATERAL INFLOWS & INJECTIONS
INITIALIZE INITHY, FACTOR, INITWQ
N1
CYCLE
BEGIN CALCULATION BY TIDAL CYCLE
FIRST CYCLE
YES
NO
A2
INPUT2 & LATJEC B.C. OUTPUT SPECS.
A2
UPOUT
UPDATE OUTPUT FILES
B2
DEL-T
BEGIN CALCULATION BY TIME STEP
CALC
HYDRAULICS
READ
READ
READ IN HYDRAULICS
HYDCALC
CALCULATE HYDRAULICS
WQCALC
WLATQ TREAT LATERAL INFLOWS
WQJECT TREAT INJECTIONS
FACTOR SET OF EQUATION FACTORS
BRANCH ON W.Q. PARAMETER
S E3
T F4
CBOD G3
NH3 A4
NO2 C5
NO3 C5
PHYS C5
ZOON C5
PON C5
DON C5
NBOD J3
DO B4
FCOL H4
A4
NH3
CALL SOURCS CALL CONSRV
B4
DO
CALL DODSR
SETSOURC
SET UP THE SOURCE TERM
J3
NBOD
CALL CONSRV
E3
SALT
CALL CONSRV
REACH
REACH SOLVE EQUATIONS
F4
TEMP
CALL CONSRV CALL FLUX
HOUSEKEEP & STORE SOLUTION
G3
CBOD
CALL DECAY
LAST TIME STEP
NO
YES
B2
H4
FCOL
CALL DECAY
OUTPUT OUTPUT THIS CYCLE
LAST CHANCE
NO
YES
N1
EXIT

FIGURE 4.2 DETAILED PROGRAM FLOW CHART

V. PREPARATION OF INPUT DATA

5.1 Description of Card Groupings

The following sections (5.2 - 5.10) include the input data required to run the model. Each card with its associated input information is listed on a separate page.

Card Group A includes information regarding solution options. Here it is stipulated which solutions (hydraulic and water quality) will be executed and which water quality parameters will be modeled. Time parameters stipulating the duration of the run and the time step of integration, and the network topology (identification and sequence of reaches) is also provided.

Card Group B provides the geometric information (i.e., the physical properties of the channel), and the computational mesh spacing and initial conditions required for the hydraulic solution. This group is repeated for each reach in the sequence as given in Group A.

Card Group C provides values of rate coefficients for those water quality parameters being modeled. The coefficients may be specified for the entire network (cards c-b and c-c) or may be specified for each individual reach (cards c-d and c-e). If the user does not with to specify values, the program will automatically use those default values listed in Tables 5.3, 5.4, and 5.5. In this card group, the computational mesh spacing for water quality calculations and initial conditions for water quality parameters are also specified.

Card Group D describes the location, magnitude and quality of any lateral inflows being considered. Lateral inflows are considerd for both the hydraulic and water quality solutions.

Card Group E describes the same information for any injections (e.g. sewage treatment plant or waste heat discharges) of water quality parameters. Injections are considered only in the water quality solution. For hydraulic purposes they are considered passive, that is they have no effect on the flow field in the receiving water. If in actuality the flow rate of a discharge is significant when compared to the flow rate of the receiving water, then it must be modeled as a lateral inflow of zero width (i.e. DXLAT = 0.0 on card d-c-1).

Card Group F stipulates the hydraulic boundary conditions to be applied at each node in the network. These have been described previously in Section 3.2.

Card Group G allows the user to selectively view output from the hydraulic solution. The output can be requested in two forms - (1) a hydrograph which displays the parameters at a given mesh point as a function of time and (2) a hydraulic profile which displays the parameters at a given time increment as a function of distance. The hydraulic parameters displayed are surface elevation, depth, discharge and velocity.

Card Group H stipulates the water quality boundary conditions to be applied at each node in the network. These have been described previously in Section 3.3.

Card Group I allows the user again to selectively view output. The water quality solution also may be displayed in two forms - (1) water quality graphs, i.e., parameters as a function of time, and (2) water quality profiles, i.e., parameters as a function of distance. All of the water quality parameters stipulated on card A-d will automatically be displayed.

The sequence of the input card groups is important to note. Certain of the card groups (D,E,F,G,H,I) for particular cases must be repeated several times corresponding to the number of periods for which the solution is executed. Refer to cards A-b and A-c. If the hydraulic solution is transient, IOPT(2) = 2, groups D, F, and G must be repeated. If the water quality boundary and inflow specifications are made for several time periods, JOPT(2) = 2, groups E, H, and I must be repeated. For a simple example, consider the case of a waterway being modeled for three time periods with IOPT(2) = 2 and JOPT(2) = 2. Then the sequence of the input data card groups would be as follows: A, B, C, D, E, F, G, H, I, D, E, F, G, H, I, D, E, F, G, H, I.

5.2 CARD GROUP A

SOLUTION OPTIONS, TIME PARAMETERS, NETWORK TOPOLOGY

CARD	TYPE
0	Switch to Disable Execution
a	Title Card
b	Hydraulic Solution Options
c	Water Quality Solution Options
d	Water Quality Parameter Options
e	Prototype Time Parameters
f	Network Parameters
g	Reach-Node Connectivity Cards (one per reach)
h	Control Structure Identification Cards

CARD A-0

SWITCH TO DISABLE EXECUTION							
LEWSW							
I10							
10	20	30	40	50	60	70	80

LEWSW = 0	Execution enabled
LEWSW ≠ 0	Execution disabled, input data will be processed

TITLE CARD

DESCRIPTION OF RUN IDENTIFYING OUTPUT FOR LATER REFERENCE

FORMAT (20A4)

10	20	30	40	50	60	70	80

CARD A-a

CARD A-b

HYDRAULIC SOLUTION OPTIONS							
IOPT(1)	IOPT(2)	IOPT(3)	IOPT(4)	IOPT(5)			
I 10	I 10	I 10	I 10	I 10			
10	20	30	40	50	60	70	80

IOPT(1) = 1, solution computations executed
2, solution computations deleted

IOPT(2) = 1, steady state river or quasi-steady state estuary (i.e. repreating tidal hydraulics)
2, transient solution

IOPT(3) = 1, solution storage to sequential data set executed
2, solution storage to sequential data set deleted

IOPT(4) = 1, river network - waterway characterized by single time period
2, estuary network - waterway characterized by more than one time period

IOPT(5) = 1, hydraulic initialization read from sequential data set
2, hydraulic intialization taken from data deck

If IOPT(2) = 2, Card Groups D, F, and G must be repeated as many times as there are periods (e.g. for a transient, estuary network of five time periods, five sets of card groups D, F, and G must be included.)

WATER QUALITY SOLUTION OPTIONS

The computer program assumes that if the hydraulic solution is deleted and the water quality solution is executed, then the hydraulics necessary for the water quality solution will be read from storage, i.e. IOPT(5) = 1

JOPT(1)	JOPT(2)	JOPT(3)					
I 10	I 10	I 10					
10	20	30	40	50	60	70	80

JOPT(1) = 1, solution computations executed
2, solution computations deleted

JOPT(2) = 1, boundary and inflow specifications made for one time period (for an estuary, these will be used for each tidal period)
2, boundary and inflow specifications made for one or more time periods

JOPT(3) = 1, solution storage to sequential data set executed
2, solution storage to sequential data set deleted

If JOPT(2) = 2, Card Groups E, H, and I must be repeated as many times as there are periods.

CARD A-c

CARD A-d-1

WATER QUALITY PARAMETER OPTIONS

Delete if only hydraulics is being computed, i.e. IOPT(1) = 1 and JOPT(1) = 2

NPARM	NTAY						
I 10	I 10						
10	20	30	40	50	60	70	80

NPARM - Total number of water quality parameters being modeled, whether calculated or read-in from a previous calculation (see Table 5.1).

N-cycle is counted as one parameter in this case. (There are 7 N-cycle components)

NTAY - integer multiple of Taylor Dispersion Coefficient to account for lateral mixing. ($E = NTAY * 77\ U(t)\ R_h^{5/6}$)
If left blank NTAY defaults to 1.

Table 5.1

Water Quality Parameter Abreviations (N-Cycle as a group)

(Card A-d-2)

Abreviation	Parameter
S	Salinity
T	Temperature
CBOD	Biochemical oxygen demand (Carbona ceous)
NUTR	Nutrients: 1) Ammonia Nitrogen, 2) Nitrite Nitrogen, 3) Nitrate Nitrogen, 4) Phytoplankton Nitrogen, 5) Zooplankton Nitrogen, 6) Particulate Organic Nitrogen, 7) Dissolved Organic Nitrogen
DO	Dissolved Oxygen
FCOL	Fecal Coliforms

Table 5.2

Complete Symbolic Identification of Water Quality Parameters and Sequence of Identification

Abreviation	Parameter
S	Salinity
T	Temperature
CBOD	Carbonaceous Biochemical Oxygen Demand
NH3	Ammonia nitrogen
NO2	Nitrite nitrogen
NO3	Nitrate nitrogen
PHYN	Phytoplankton nitrogen
ZOON	Zooplankton nitrogen
PON	Particulate organic nitrogen
DON	Dissolved organic nitrogen
DO	Dissolved oxygen
FCOL	Fecal coliforms

PARAMETER CARD

Delete if only hydraulics is being computed, i.e. IOPT(1) = 1 and JOPT(1) = 2

One card per parameter being modeled (nutrients as a group)

WQPAR(I)	INOP	OUTOP	DOCALC				
A4, 6X	I 10	I 10	I 10				
10	20	30	40	50	60	70	80

WQPAR(I) - Abrevation of Water Quality Parameter as given in Table 5.1 .
(start in card column 1)

INOP = 0 or blank, Parameter is calculated
1, Parameter is read-in (Temperature and BOD only)
2, Parameter is of constant concentration as specified by initial conditions (Temperature and BOD only)

OUTOP = 0 or blank, no offline storage or output
1, output stored on sequential output file

DOCALC = blank except for Dissolved Oxygen (D.O.)

= 1, DO calculated as a function of C-BOD alone
= 2, DO calculated as a function of N-BOD
= 3, DO calculated as a function of both C-BOD and N-BOD

CARD A-d-2

CARD A-e

PROTOTYPE TIME PARAMETERS

NPER	NINC	PERIOD	RATIO	MAXITR	EPS	LPER	NRINC
I 10	I 10	F 10.5	F 10.5	I 10	F 10.5	I 10	I 10
		seconds			decimal		
10	20	30	40	50	60	70	80

See Next Page for Description of Parameters

NPER = number of periods the solution is to propagate. Specify 1 in the case of a river system.

NINC = number of time increments within each period for the hydraulic model. Δt = PERIOD/NINC. See discussion earlier in manual for stability criteria $\Delta t \leq 5.5\ \Delta x/U + c$

PERIOD = length of prototype time period in seconds. In estuaries, it is convenient to use the tidal period. For river systems, this is the total time being modeled.

RATIO = ratio of the water quality time increment to the hydraulic time increment.

$$= \frac{\Delta t_{WQ}}{\Delta t_H}\text{, such that number of quality increments = integer } \frac{\text{(number of hydraulic increments)}}{\text{ratio}}$$

(May be left blank if water quality computation is to be deleted.)

MAXITR = maximum number of iterations allowed the program to compute a steady-state hydraulic initial condition (for an estuary the iteration is equal to the period; for a river the iteration is equal to Δt_H)

EPS = the maximum allowed change in the discharges at each mesh point from one tidal period to the next. This defines a steady-state initial condition.

$$\text{EPS} < 1.0 - (Q_{T-1}/Q_T)$$

LPER = number of lead-in periods of hydraulics to be read from tape before solution starts. This parameter is only used for extending file containing hydraulic solution and for water quality computations in an estuary.

NRINC = number of time increments of lead-in for river studies (excluding initial data). Use only if file is being extended.

NETWORK PARAMETERS							
NREACH	NNODE	NCTR					
I 10	I 10	I 10					
10	20	30	40	50	60	70	80

NREACH = number of reaches in the network

NNODE = number of nodes in the network

NCTR = number of control structures

CARD A-f

REACH-NODE CONNECTIVITY CARDS (ONE PER REACH)

Repeat the connectivity cards for all reaches. The reaches can be given any numerical number, however, the nodes in any network must be numbered consecutively from 1 to n.

K	IRCH(K)	IREACH(K,1)	IREACH(K,2)				
I 10	I 10	I 10	I 10				
10	20	30	40	50	60	70	80

K = sequence number of reach numbers

IRCH(K) = numerical identification of the reach to which the information applies

IREACH(K,1) = number of the node at the upstream end of the reach (the end from which the distances are given is the upstream end)

IREACH(K,2) = number of the node at the downstream end of the reach

Ex:

K	IRCH	IREACH(K,1)	IREACH(K,2)
1	10	1	2
2	13	2	3
3	15	2	4
4	8	3	5
5	7	4	5

CONTROL STRUCTURE IDENTIFICATION CARDS - Necessary if NCTR $\neq$ 0

This card must be repeated according to the number of control structures, NCTR indicated on card A-f - delete if NCTR = 0

ICRS(I,1)	ICRS(I,2)						
I 10	I 10						
10	20	30	40	50	60	70	80

ICRS(I,1) = node at upstream end of control structure

ICRS(I,2) = node at downstream end of control structure

5.3 CARD GROUP B

HYDRAULIC DESCRIPTION OF THE REACHES

CARD	TYPE
a	Reach Identification
b	Reach Characterization Card
c	Reach Parameters
d	Elevation Table Parameters
e	Cross-section Geometry Parameters (repeat for each cross-section)
f	Irregular Cross-section, Constant or Variable Top Width
g	Irregular Cross-section, Constant Top Width
h	Irregular Cross-section, Variable Top Width

NOTE: The cards in Group B constitute a package for a single reach. This package of cards is repeated for each reach, and must be in the sequence specified by the reach-node connectivity cards.

CARD B-a

REACH IDENTIFICATION							
DESCRIPTIVE INDENTIFICATION OF THE REACH							
FORMAT (20A4)							
10	20	30	40	50	60	70	80

CARD B-b

REACH CHARACTERIZATION CARD

JK	IS(K)	IP(K)	ISL(K)		ICE(K)	IDTABL(K)	
I 10	I 10	I 10	I 10	10x	I 10	I 10	
10	20	30	40	50	60	70	80

JK = numerical identification (IRCH(K)) of the reach to which the information applies, the reaches must be in the same order as that specified by reach-node connectivity table

IS(K) = specifies the shape of the channel cross-section within the reach
1, irregular
2, rectangular
3, trapezoidal
4, circular

IP(K) = 1, prismatic channel along the length of the reach
2, non-prismatic channel (varying width or land depth)

ISL(K) = 1, botton slope of reach constant and given on Card B-c
2, bottom slope variable and computed from bottom elevations at each section

ICE(K) = 0 or blank, no ice cover
1, ice cover; hydraulic radius will take cover into account

IDTABL(K) = 1, print interpolated tables of geometric parameters
0, no table printout

REACH PARAMETERS

SL(K)	SS(K)	XMANN(K)		TL(K)	DX(K)		
F 10.5	F 10.5	F 10.5	10x	F 10.5	F 10.5		
ft/ft	ft/ft	$ft^{1/6}$		ft.	ft.		
10	20	30	40	50	60	70	80

SL(K) = bottom slope of the channel if it is to be specified. Can be left blank if ISL(K) = 2

SS(K) = side slope for a trapezoidal channel. Can be left blank if IS(K) ≠ 3 (SS = vertical per unit horizontal)

XMANN(K) = Manning coefficient, for the entire reach. This can be overridden at individual sections (Card B-e)

TL(K) = total length of the reach from upstream to downstream node

DX(K) = initial estimate of the computational mesh spacing in reach K. Final value of DX(K) is computed in the program to make sure that the reach length is divided into equal increments (in feet). DX(K) must be compatible with the hydraulic time increment Δt, NINC Card A-e.

CARD B-c

ELEVATION TABLE PARAMETERS

An internal table of parameters as a function of elevation will be generated. IIZ is the number of entries in this table, and should be a number sufficient to permit reasonable interpolation of values from the table. H1(K) and H2(K) represent the expected minimum and maximum water surface elevations

NS(K)	IIZ(K)	H1(K)	H2(K)				
I 10	I 10	F 10.5	F 10.5				
		ft.	ft.				
10	20	30	40	50	60	70	80

NS(K) = number of cross-sections in the reach at which geometric information is provided. It must be at least 1, as will be seen in the discussion preceding the definitions of cross-section geometry parameters.

IIZ(K) = number of entries in elevation tables of geometric parameters.

H1(K) = minimum elevation entry for reach K in the case where the elevation tables are to be calculated for a rectangular, trapezoidal, circular or constant top width irregular cross-section. This is the minimum expected water surface elevation for the reach.

H2(K) = maximum elevation entry for reach K in the same cases. This is the maximum expected water surface elevation.

For the case of an irregular cross-section, variable topwidth, it is not necessary to specify H1(K) and H2(K).

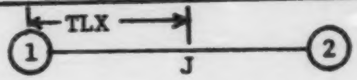
CARD B-d

CROSS-SECTION GEOMETRY PARAMETERS (repeat for each cross-section)

Cards B-e, B-f, B-g and B-h constitute the cross-section subpackage, which must be supplied for each data cross-section indicated by the parameter NS(K). For a prismatic cross-section of regular geometric shape (IP(K) = 1) only card B-e is necessary. Cards B-f and either B-g or B-h are supplied only if the cross-section shape is specified as irregular(IS(K) = 1)

TLX(K,J)	BW(K,J)	BEL(K,J)	R(K,J)	Z(K,J)	Q(K,J)	FCOEF(K,J)	
F 10.5	F 10.5	F 10.5	F 10.5	F 10.5	F 10.5	F 10.5	
ft.	ft.	ft.	ft.	ft.	cfs		
10	20	30	40	50	60	70	80

TLX(K,J) = distance from upstream end in feet to cross-section J in reach K.



BW (K,J) = bottom width at TLX(K,J). Supplied for rectangular and trapezoidal cross-section shapes. Fill in if IS(K) = 2 or 3, otherwise leave blank.

BEL(K,J) = bottom elevation at TLX(K,J). Required when bottom slope is not specified, and required at final cross-section of each reach when slope is specified for prismatic section. Final cross-section of reach must be used when only one section is described.

R(K,J) = pipe radius at TLX(K,J). Leave blank if channel shape is not circular. (At present, the program allows only a constant radius pipe.)

Z(K.J) = estimate of initial water surface elevation at TLX(K,J).

Q(K,J) = estimate of initial discharge at TLX(K,J).

FCOEFF(K,J) = Manning's coefficient for this section. This value will replace the value (if any) specified for the entire reach. Can be left blank if coefficient defined on Card B-c.

CARD B-e

CARD B-f

IRREGULAR CROSS-SECTION, CONSTANT OR VARIABLE TOP WIDTH

Card B-f is supplied only if the cross-section shape is specified as irregular, thus IS(K) = 1.

ITW							
I 10							
10	20	30	40	50	60	70	80

ITW = 1, for constant top width

ITW = 2, for variable width

IRREGULAR CROSS-SECTION, CONSTANT TOP WIDTH

Card B-g is supplied only if IS(K) = 1 and ITW = 1. Refer to figure below for procedure of calculating section parameters.

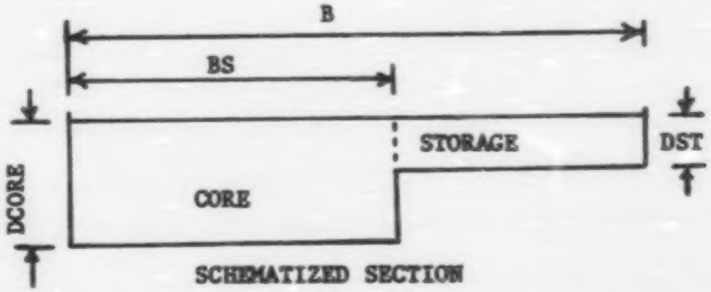
B	BS	DST	DCORE				
F 10.5	F 10.5	F 10.5	F 10.5				
ft.	ft.	ft.	ft.				
10	20	30	40	50	60	70	80

B = total topwidth in feet

BS = core topwidth in feet

DST = schematized depth of storage area

DCORE = schematized depth of core area



SCHEMATIZED SECTION

CARD B-g

IRREGULAR CROSS-SECTION, VARIABLE TOP WIDTH

Card B-h is supplied only if IS(K) = 1 and ITW = 2. This card is to be repeated, corresponding to the number of elevation entries indicated by IIZ(K). These cards must be arranged in order of increasing depth.

HEAD(K,J,I)	TW(K,J,I)	CW(K,J,I)	AREA(K,J,I)	WPERM(K,J,I)	TAREA(K,J,I)		
F 10.5	F 10.5	F 10.5	F 10.5	F 10.5	F 10.5		
ft.	ft.	ft.	ft.^{2}	ft.	ft.^{2}		
10	20	30	40	50	60	70	80

HEAD(K,J,I) = water surface elevation entry I for cross-section J in reach K, where I ranges from 1 to IIZ(K)

TW(K,J,I) = total top width for entry I

CW(K,J,I) = core width for entry I

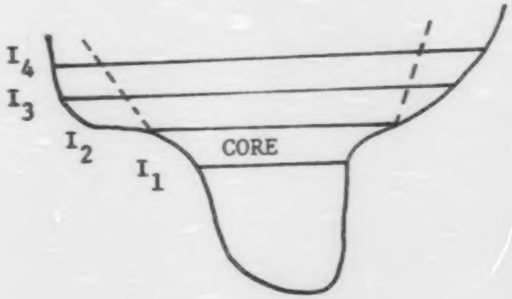
AREA(K,J,I) = core area for entry I

WPERM(K,J,I) = wetter perimeter along core for entry I

TAREA(K,J,I) = total cross-sectional area for entry I (area of core plus area of storage)

See Figure below for method of determining section parameters

Range of HEAD should correspond to particular head of cross-section.



CARD B-h

5.4 CARD GROUP C

WATER QUALITY DESCRIPTION OF THE REACHES

CARD	TYPE
a	Header - Identification Card
b	Parameter Card: Network Specification
c	Parameter Override Cards: Network Specification
d	Mesh Point Parameters
e	Reach Override Identification
f	Initial Condition Cards

NOTE: This card group must be omitted if the water quality computations are deleted, JOPT(1) = 2.

As the water quality parameter possibilities consist of as many as 12, the form of definition has been designed to give the user flexisility in specifying coefficients, mesh-point locations and initial conditions. The parameter coefficients can be specified at two levels. The first is for the entire network, the second is for an individual reach. Default values (Table 5.3,5.4, 5.5) may be used or the user can override default values at either level. Figure 5.1 illustrates the organization of input data for this Card Group.

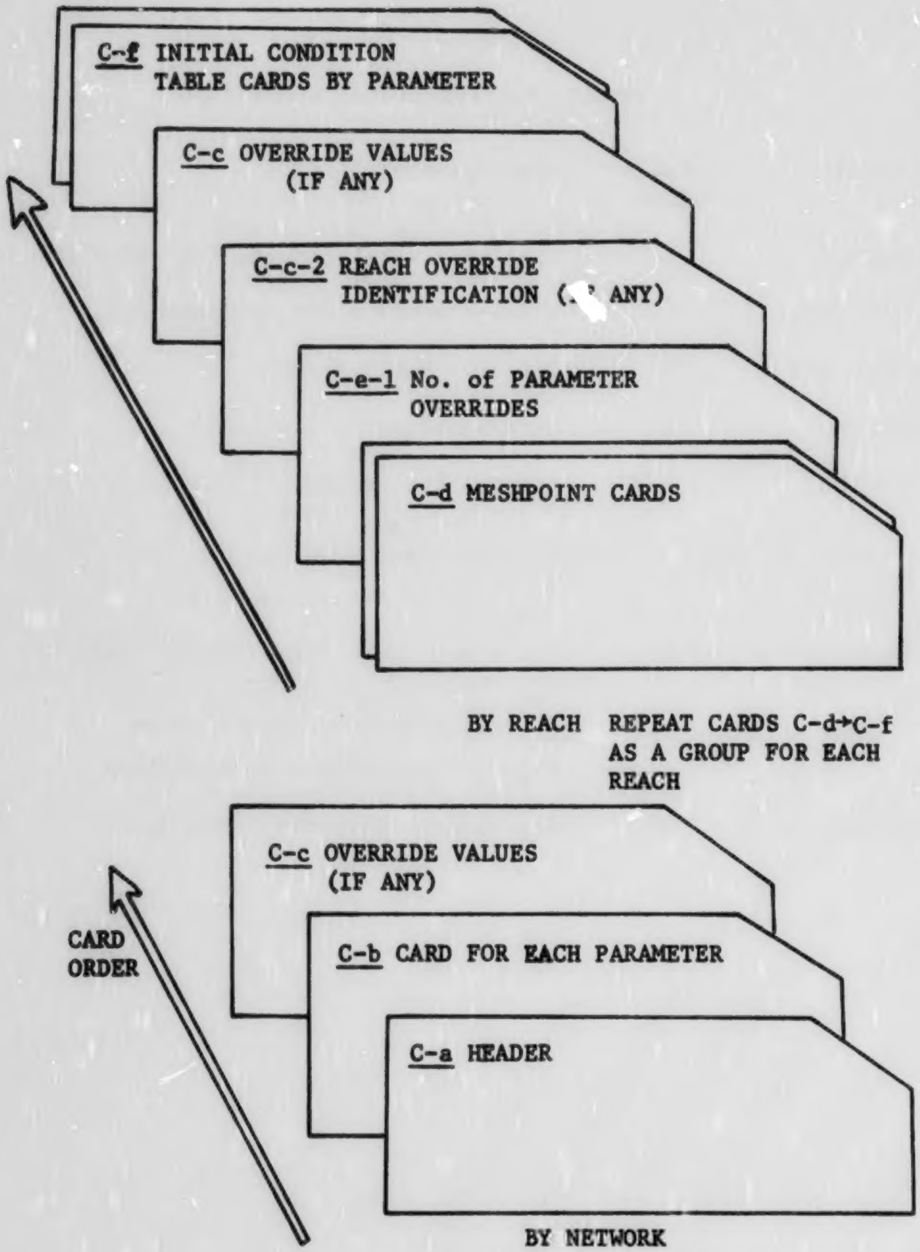

C-f INITIAL CONDITION TABLE CARDS BY PARAMETER
C-c OVERRIDE VALUES (IF ANY)
C-c-2 REACH OVERRIDE IDENTIFICATION (IF ANY)
C-e-1 No. of PARAMETER OVERRIDES
C-d MESHPOINT CARDS
BY REACH
REPEAT CARDS C-d→C-f AS A GROUP FOR EACH REACH
C-c OVERRIDE VALUES (IF ANY)
CARD ORDER
C-b CARD FOR EACH PARAMETER
C-a HEADER
BY NETWORK

FIGURE 5.1

SCHEMATIC REPRESENTATION

OF CARD GROUP C

TABLE 5.3

DEFAULT METEOROLOGICAL CONDITIONS

Symbolic Name	Default Values	Descriptions
ATM(IMC)	0.	Time from the beginning for entry IMC in hours
ATAMB(IMC)	60.	Ambient temperature in degrees F
ARELG(IMC)	75.	Relative humidity (%)
AW2(IMC)	10.	Wind velocity at 2 m (mph)
ARFT(IMC)	1800.	Net solar flux (BTU/ft^2/day) $\phi_{sf} = \phi_s - \phi_{sr}$ where ϕ_s = incident solar flux ϕ_{sr} = reflected solar flux
ARFA(IMC)	2500.	Net atmospheric flux (BTU/ft^2/day) $\phi_{as} = \phi_a - \phi_{ar}$ where ϕ_a = incident atmospheric flux ϕ_{ar} = reflected atmospheric flux
APRESS(IMC)	760.	Atmospheric pressure in mm Hg.

TABLE 5.4

DEFAULT QUALITY CONDITIONS

Symbolic Names	Default Values	Descriptions
C-B.O.D.		
KB20	0.3	Decay coefficient (day^{-1}) at 20°C where $KBOD = KB20 \times QT^{(T-20)}$
QT	1.047	Empirical coefficient in above equation
D.O.		
KD20	10.8	Reaeration coefficient (day^{-1}) at 20°C where $KDO = (KD20 \frac{V^{0.60}}{H^{1.40}}) QT^{(T-20)} \times H \times \frac{\text{Total Topwidth}}{\text{Total Area}}$ where; V = absolute velocity H = depth in units of day^{-1} (base e)
QT	1.016	Empirical coefficient in above equation
Fecal Coliforms		
KFCOL20	2.8	Decay coefficient (day^{-1}) at 20°C, where $KFCOL = KFCOL20 \times QT^{(T-20)}$
QT	1.045	Empirical coefficient in above equation

TABLE 5.5

DEFAULT NUTRIENT COEFFICIENTS

Nutrient Coefficient Number	Default Values	Descriptions
1	0.09	Rate of bacterial hydrolysis (value/day-degrees C)
2	1.065	Temperature coefficient (no units)
3	0.008	Zooplankton respiration rate (value/day at 20 degrees C)
4	0.008	Phytoplankton respiration rate (value/day at 20 degrees C)
5	0.20	Ammonia oxidation rate (value/day at 20 degrees C)
6	212.36	Optimum solar radiation for photosynthesis (ft- BTU/ft^2/Day)
7	0.05	Natural light extinction coefficient (value/ft.)
8	0.06	Phytoplankton self shading (value/(mg/1)-ft.)
9	30.0	Optimum temperature for NH3-N and NO3-N uptake by phytoplankton (degrees C)
10	2.0	Maximum NH3-N uptake rate by phytoplankton (value/day)
11	0.3	Half saturation constant for NH3-N (mg/1)
12	0.25	Nitrite oxidation rate (value/day at 20 degrees C)
13	1.0	Maximum NO3-N uptake rate by photoplankton (value/dav)
14	0.7	Half saturation constant for NO3-N (mg/1)
15	0.1	Concentration of NH3-N above which NO3-N uptake is minimum (mg/1)

TABLE 5.5

(continued)

Nutrient Coefficient Number	Default Values	Description
16	0.05*	Minimum NO3-N uptake rate of photoplankton in the presence of NH3-N (value/day)
17	0.03*	Phytoplankton lysis (value/day)
18	0.03*	Phytoplankton death and excretion (value/day)
19	0.075*	Minimum uptake rate of zooplankton during the day (value/day)
20	25.0	Optimum temperature for zooplankton uptake of phytoplankton (degrees C)
21	1.5*	Maximum zooplankton uptake rate (value/day)
22	1.0*	Half saturation constant for PHY-N (mg/l)
23	0.1	Zooplankton lysis rate (value/day)
24	0.30*	Conversion of PON to DON (value/day)

CARD C-a

WATER QUALITY IDENTIFICATION

This is a general identification card for a water quality run

WATER QUALITY DESCRIPTION OF THE REACHES

FORMAT(20A4)

10	20	30	40	50	60	70	80

CARD C-b

WATER QUALITY PARAMETER COEFFICIENTS BY PARAMETER: NETWORK SPECIFICATION

One card for each Parameter being calculated. If Network Specification is selected follow by a Parameter Subgroup (Card C-c).

WQPAR(I)	KEY	ISOLR	TOD				
A4,6X	I 10	I 10	F 10.0				
			decimal hours				
10	20	30	40	50	60	70	80

WQPAR(I) = Abreviation of the parameter (S, T, CBOD, NUTR, DO, FCOL of Table A-1)

KEY = 0 or blank, no Network Specification, default values are taken for the entire network(see Tables 5.3,5.4, 5.5). These values can be overriden by reach.

= 1, the Specification is by Network subject to override by reach.

There are no default values for salinity: KEY = 1 for salinity always.

For Nutrients (Nitrogen Model) only:

ISOLR = 0, Solar Radiation by internal clock (half-sine)
= 1, Solar Radiation by Meteorological input

TOD = Starting Time-of-Day for internal clock (ISOLR = 0)
Units are decimal hours from 0 to 24.

CARD FOR SALINITY							
DISP	REFS	REFL					
F 10.0	F 10.0	F 10.0					
ft^2/sec	ppm	ft.					
10	20	30	40	50	60	70	80

DISP = salinity region dispersion parameter

REFS = salinity region reference salinity, S_o(=ocean salinity)

REFL = salinity region reference estuary length, L(= estuary length)

Since there are no default values for salinity parameter coefficients, this card must be included if salinity is being calculated.

CARD C-c-s

CARD C-c-T1

OVERRIDE CARD - TEMPERATURE
Temperature Coefficients, Meteorological Conditions
Number of Time Entries

NMC							
I.10							
10	20	30	40	50	60	70	80

NMC = number of meteorological time entries
= 1, for constant conditions

CARD C-c-T2

METEOROLOGICAL CONDITIONS BY TIME

(NMC cards, where IMC is the card number from 1 to NMC)

ATM(IMC)	ATAMB(IMC)	ARELH(IMC)	AW2(IMC)	ARFS(IMC)	ARFA(IMC)	APRESS(IMC)	
F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	
hours	°F	%	mph	BTU/ft^2/day)	BTU/ft^2/day	mm. Hg	
10	20	30	40	50	60	70	80

ATM(IMC) = time from the beginning for entry IMC (hours)

ATAMB(IMC) = ambient temperature (°F)

ARELH(IMC) = relative humidity (%)

AW2(IMC) = wind velocity at 2 m. (miles/hour)

ARFS(IMC) = net solar flux (BTU/ft^2/day)

$= \phi_s - \phi_{sr}$

where ϕ_s = incident solar flux

ϕ_{sr} = reflected solar flux

ARFA(IMC) = net atmospheric flux (BTU/ft^2/day)

$= \phi_a - \phi_{ar}$

where ϕ_a = incident atmospheric flux

ϕ_{ar} = reflected atmospheric flux

APRESS(IMC) = atmospheric pressure (mm Hg)

OVERRIDE CARD - BOD

BOD COEFFICIENT CARD

CBOD	KB20	QT					
A4,6X	F 10.0	F 10.0					
	1/day(base e)						
10	20	30	40	50	60	70	80

KB20 = B.O.D. decay coefficient in the equation in 1/day to the base e

$$KBOD = KB20\ QT^{(T-20)}$$

QT = Empirical coefficient

Default values are KB20 = 0.3

QT = 1.047

CARD
C-c-CBOD

CARD C-c-N

OVERRIDE CARD - NUTRIENTS

N-Cycle Coefficient Overrides to Default Values of Table C-3

NUTOR							
I 10							
10	20	30	40	50	60	70	80

NUTOR = number of overriden coefficients to be specified on the following cards (one/card)

CARD C-c-N2

N-CYCLE COEFFICIENT OVERRIDE CARD
(One per coefficient to be overriden)

SYM	VALUE						
I4,6X	F 10.0						
10	20	30	40	50	60	70	80

SYM = the number of the nutrient coefficient as specified in Table 5.5

VALUE = the new value of the coefficient

CARD C-c-DO

OVERRIDE CARD D.O.

Dissolved Oxygen Coefficient Card

DO	KD20	QT					
A4,6X	F 10.0	F 10.0					
	day^{-1}(base e)						
10	20	30	40	50	60	70	80

KD20 = reaeration coefficient in the expression

$$KDO = (KD20 \frac{V^{0.60}}{H^{1.4}})QT^{(T-20)} \times H \times \frac{\text{Total Topwidth}}{\text{Total Area}}$$

Default is KD20 is 10.8 base e

QT = empirical coefficient in the above equation
default = 1.016

CARD
C-c-FCOL

OVERRIDE CARD Fecal Coliforms Fecal Coliform Coefficient Card							
FCOL	KFCOL20	QT					
A4,6X	F 10.0	F 10.0					
	1/day(base e)						
10	20	30	40	50	60	70	80

KFCOL20 = decay coefficient at 20°C, where

$KFCOL = KFCOL20 \times (QT)^{(T-20)}$ in 1/day, base e

default value is $2.8\,day^{-1}$ for KFCOL20 and 1.045 for QT

QT = empirical coefficient in above equations
QT default = 1.045

CARD C-d-1

MESHPOINT CARDS

WATER QUALITY REACH DATA - MESHPOINTS

One card for each reach followed by other reach cards

REACH	K	MESHPT(K)					
10X	I 10	I 10					
10	20	30	40	50	60	70	80

K = numerical identification of the reach
(These should be in the order specified in card A-g)

MESHPT(K) - Number of Meshpoints defining element boundaries for reach K. For each reach the user must define the locations at which an element starts and ends. A third point is internally computed at the mid-point of each element. At the specified locations and their midpoints the finite difference calculations are made.

CARD
C-d-2 etc.

MESHPOINT LOCATION CARDS (7 meshpoints per card)							
X(I)	X(I + 1)	X(I + 2)	X(I + 3)	X(I + 4)	X(I + 5)	X(I + 6)	
F 10.0	F 10.0	F 10.0	F 10.0	F 10.0	F 10.0	F 10.0	
ft.	ft.	ft.	ft.	ft.	ft.	ft.	
10	20	30	40	50	60	70	80

X(I), X(I + 1) etc. = location of meshpoints in feet from upstream node

As many cards as necessary of the above format should be prepared. (7 times per card). The values should be in numerical order. The first value X (1) must be 0., the last value X (MESHPOINT (K)) must be equal to TL(K), total length of the reach defined in Card B-c.

CARD C-e-1

REACH OVERRIDE IDENTIFICATION Parameter Overrides by Reach							
OVERRIDES	K	NMPAR					
10X	I 10	I 10					
10X							
10	20	30	40	50	60	70	80

K = identification number of this reach

NMPAR = Number of Parameters whose Network specified coefficients are being overriden.
(N-Cycle is considered one parameter in this case).

CARD
C-e-2 etc

PARAMETER IDENTIFICATION CARD							
WQPAR(I)							
A4							
10	20	30	40	50	60	70	80

WQPAR(I) = Abreviation of the parameter. (S, T, CBOD, NUTR, DO, FCOL)

This card must be followed by the redefinition of the coefficients using cards of format C-c-S, C-c-T, C-c-BOD, C-c-N, C-c-DO, C-c-FCOL

CARD
C-f-1

INITIAL CONDITION CARDS

Initial Conditions for this Reach by Parameter

NAME	NPTS						
A4 6X	I 10						
10	20	30	40	50	60	70	80

NAME = One to four letter identification of the parameter, in the following sequence:

S - Salinity
T - Temperature (degrees F)
CBOD - Biochemical Oxygen Demand (Carbonaceous)
NH3 - Ammonia nitrogen
NO2 - Nitrite nitrogen
NO3 - Nitrate nitrogen
PHYN - Phytoplankton nitrogen
ZOON - Zooplankton nitrogen
PON - Particulate organic nitrogen
DON - Dissolved organic nitrogen
DO - Dissolved oxygen
FCOL - Fecal coliforms

NPTS - number of points defining the Initial Condition as given by the following cards. If NPTS = 1, the value is applying over the entire reach. (If NPTS > 1, initial conditions must be specified at least at the upstream and downstream ends of the reach in order to avoid negative initial conditions due to the program interpolation scheme).

CARD C-f-2

INITIAL CONDITION TABLE

(One card for each location)

X	CON						
F 10.0	F 10.0						
feet							
10	20	30	40	50	60	70	80

X = distance from upstream node to location at which initial concentration is specified. (Can be anything for case of NPTS = 1)

CON = Initial Concentration

5.5 CARD GROUP D

LATERAL INFLOW DATA

CARD	TYPE
a	Lateral Inflow Identification Card
b	Number of Lateral Inflows
c	Lateral Inflow Parameters
d	Lateral Inflows

If IOPT(2) = 2 this card group must be repeated as many times as there are periods.

CARD D-a

LATERAL INFLOW IDENTIFICATION CARD

After the identification cards, D-a and D-b, there is a package of cards which is repeated for all lateral inflows.

DESCRIPTION OF THE LATERAL INFLOWS							
FORMAT (20A4)							
10	20	30	40	50	60	70	80

Lateral inflows can be either inflows of streams from sub-basins or inflows of quality constituents.

CARD D-b

NUMBER OF LATERAL INFLOWS

If there are no lateral inflows, NLAT = 0, the computer will skip to the next card group. Otherwise, it will expect the lateral inflow data from cards D-c and D-d.

NLAT							
I 10							
10	20	30	40	50	60	70	80

NLAT = total number of lateral inflows

LATERAL INFLOW PARAMETERS

Cards D-c and D-d constitute a package and must be repeated according to the number of lateral inflows, NLAT

IL	KLAT(IL)	XLAT(IL)	DXLAT(IL)	ILAT(IL)	IT(IL)	NPAR(IL)	
I 10	I 10	F 10.5	F 10.5	I 10	I 10	I 10	
		ft.	ft.				
10	20	30	40	50	60	70	80

IL = number of the inflow to which the information applies

KLAT(IL) = number of the reach in which inflow IL is located

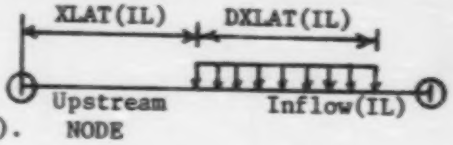
XLAT(IL) = distance to upstream end of inflow IL

DXLAT(IL) = width of inflow IL. (A point inflow can be defined by a width of 0.0).

ILAT(IL) = 1, constant lateral inflow
2, variable lateral inflow

IT(IL) = number of table entries for inflow IL. One entry is necessary for constant lateral inflow.

NPAR = number of Water Quality Parameters of non-zero concentration



CARD D-c-1

CARD D-c-2

LATERAL INFLOW PARAMETERS: WATER QUALITY PARAMETER NAMES

(Use more than one card if more than 7 parameters)

SYM(1)	SYM(2)	SYM(3)	SYM(4)	SYM(5)	SYM(6)	SYM(7)	
A4,6X	A4,6X	A4,6X	A4,6X	A4,6x	A4,6X	A4,6X	
10	20	30	40	50	60	70	80

SYM(L) - the one to four letter identification of the water quality parameter in the given sequence and as described on Table 5.2. NPAR(IL), symbols.

ONLY THOSE PARAMETERS WHOSE CONCENTRATIONS ARE NON-ZERO NEED TO BE SPECIFIED

CARD D-d

LATERAL INFLOWS

Repeat this card for NPAR(IL) greater than 5, using the same format (Concentration Specifications in columns 21-70)

TIL(IL,I)	QLAT(IL,I)	CLAT(IL,I,1)	CLAT(IL,I,2)	CLAT(IL,I,3)	CLAT(IL,I,4)	CLAT(IL,I,5)	
F 10.0	F 10.0	F 10.0	F 10.0	F 10.0	F 10.0	F 10.0	
seconds	cfs/ft						
10	20	30	40	50	60	70	80

TIL(IL,I) = time in seconds for table entry I, relative to the beginning of the period

QLAT(IL,I) = magnitude of the inflow in cfs/ft for a distributed lateral inflow or cfs for a point inflow. One entry describes constant inflow and further entries describe variable lateral inflow.

CLAT(IL,I,L) = the specified concentration corresponding to the water quality parameter SYM(L) of card D-c-2.

5.6 CARD GROUP E

INJECTION DATA

CARD	TYPE
a	Injection Data Identification Card
b	Number of Injection Points
c	Injection Parameters
d	Injection Data

NOTE: This card group is omitted if water quality calculations are not to be executed, JOPT(1) = 2

If JOPT(2) = 2, this card group must be repeated as many times as there are periods.

CARD E-a

INJECTION DATA IDENTIFICATION CARD

After the cards E-a and E-b, there is a package of cards which is repeated for all injection data.

DESCRIPTIONS OF INJECTIONS							
FORMAT(20A4)							
10	20	30	40	50	60	70	80

CARD E-b

NUMBER OF INJECTION POINTS

If there are no injection points,NJECT = 0, the computer will skip to next card group.
Otherwise, it will expect the injection point data from cards E-c and E-d.

NJECT							
I 10							
10	20	30	40	50	60	70	80

NJECT = total number of injection locations

INJECTION PARAMETERS

CARDS E-c and E-d constitute a package and must be repeated according to the number of injection points specified, NJECT

IL	KJECT(IL)	XJECT(IL)	IJECT(IL)	ITJ(IL)	NPAR(IL)		
I 10	I 10	F 10.0	I 10	I 10	I 10		
		ft					
10	20	30	40	50	60	70	80

IL = number of the injection point to which the information applies

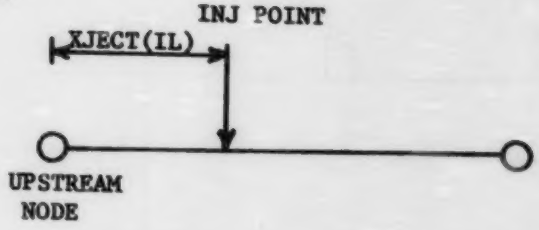
KJECT(IL) = number of the reach in which injection IL is located

XJECT(IL) = distance from upstream end of reach to injection point

IJECT(IL) = 1, constant injection rate
2, variable injection rate

ITJ(IL) = number of table entries for injection IL. One entry is necessary for constant injection rate with more as needed, to describe variable injection rate.

NPAR(IL) = number of Water Quality Parameters being injected.



CARD E-c-1

CARD E-c-2

INJECTION PARAMETERS: WATER QUALITY NAMES
(Use more than one card if there are more than 7 parameters)

SYM(1)	SYM(2)	SYM(3)	SYM(4)	SYM(5)	SYM(6)	SYM(7)	
A4,6X	A4,6X	A4,6X	A4,6X	A4,6X	A4,6X	A4,6X	
10	20	30	40	50	60	70	80

SYM(L) = the one to four letter identification of the water quality parameter in the given sequence and as described in Table 5.2. NPAR(IL) sumbols.

ONLY THOSE PARAMETERS BEING INJECTED NEED BE SPECIFIED

CARD E-d

INJECTION DATA

TJIL(IL,I)	PJECT(IL,I,1)	PJECT(IL,I,2)	PJECT(IL,I,3)	PJECT(IL,I,4)	PJECT(IL,I,5)	PJECT(IL,I,6)	PJECT(IL,I,7)
F 10.0	F 10.0	F 10.0	F 10.0	F 10.0	F 10.0	F 10.0	
Seconds	*	*	*	*	*	*	
10	20	30	40	50	60	70	80

TJIL(IL,I) = time in seconds for table entry I, relative to the beginning of the period

PJECT(IL,I,L) = the actual loading corresponding to the water quality parameter (SYM)L of Card E-c-2

*UNITS For Temperature: BTU/day
For Coliforms: No./hour
All Others: Lbs/day (N-cycle variable in terms of lbs/day-Nitrogen)

If PJECT > 7, continue next card with PJECT(IL,I,8) in columns 1-10

5.7 CARD GROUP F

HYDRAULIC BOUNDARY CONDITIONS AT THE NODES

CARD	TYPE
a	Identity Card for Hydraulic Boundary Conditions
b	Node Parameters
c	Boundary Node Conditions, NOBC(KN) = 1, 2 or 4
d	Boundary Node Condition, NOBC(KN) = 5

NOTE: This card group must be omitted if hydraulic computations are deleted, IOPT(1) = 2, that is, when the hydraulic solution is read from tape (IOPT(5) = 1).

If IOPT(2) = 2, this card group must be repeated as many times as there are periods.

CARD F-a

IDENTITY CARD FOR HYDRAULIC BOUNDARY CONDITIONS

After the identification card, F-a, there is a package of cards which is repeated for each node.

HYDRAULIC DESCRIPTIONS OF THE NODES						
FORMAT (20A4)						
10	20	30	40	50	60	70	80

CARD F-b

NODE PARAMETERS

Cards E-b,E-c or E-d constitute a package and must be repeated for each node. For interior nodes and the stage-routing cases, NOBC(KN) = 0 or 3, no more information is required and the computer will skip to the next Node Parameter Card. For NOBC(KN) = 1,2, or 4 card F-c is required. For NOBC(KN) = 5 card F-d is required.

KN	NOBC(KN)	IBC(KN)	ITX(KN)	INT(KN)			
I 10	I 10	I 10	I 10	I 10			
10	20	30	40	50	60	70	80

See Next Page for Description of Parameters

KN = number of the node for the following information

NOBC(KN) = indicates the type of condition to be applied at node KN

= 0, junction or interior node
= 1, water surface elevation prescribed
= 2, discharge prescribed
= 3, stage-routing boundary condition
= 4, rating curve (z vs Q - Table)
= 5, downstream end of control structure

IBC(KN) = indicates the time dependence of the boundary condition at node KN. In a junction node, or a downstream side of control node, the information is ignored by the computation.

= 1, constant with time
= 2, variable with time
= 3, sinusoidal with time (see card F-c)

ITX(KN) = number of table entries for the boundary conditions specifications For constant boundary conditions, and downstream side of control structure, only one card is required. Sinusoidal boundary conditions are handled with one card also, where space is provided for the height and period of oscillation. More table entries are required in IBC(KN) = 2.

INT(KN) = 1, linear interpolation of variable boundary condition data. Only if IBC(KN) = 2.
2, cosine interpolation of variable boundary condition data. Only if IBC(KN) = 2.

CARD F-c

BOUNDARY NODE CONDITIONS, NOBC(KN) = 1, 2 or 4

This card is supplied only when NOBC(KN) = 1, 2, or 4 and for IBC(KN) = 3. Card F-c also allows the user to specify a sinusoidal boundary condition as shown in the sketch below.

TIME	ZNODE	QNODE	TPER	PEAK	TLAG		
F 10.5	F 10.5	F 10.5	F 10.5	F 10.5	F 10.5		
sec.	ft.	cfs	sec.	ft.	sec.		
10	20	30	40	50	60	70	80

TIME = prototype time in seconds relative to the beginning of each individual period. If the boundary condition is constant or sinusoidal, no value need be specified.

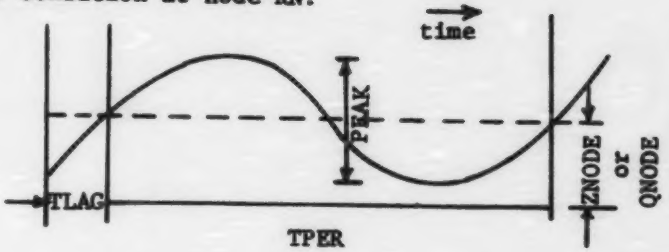
ZNODE = water surface elevation, (ft), if constant, the water surface elevation is assigned the value for J = 1. If the time dependence is sinusoidal, the mean value about which the surface elevation oscillates, is assigned the value for J = 1. (J is the subscript of time increment).

QNODE = discharge(Cfs)at node KN at time TI(KN,J). If the time dependence is constant, the discharge is assigned the value for J = 1. If the time dependence is sinusoidal, the mean discharge about which the discharge oscillates, is assigned the value for J = 1.

TPER = period of oscillation for the sinusoidal boundary condition at node KN.

PEAK = height of oscillation for the sinusoidal boundary condition at node KN.

TLAG = time lag for the sinusoidal boundary condition.



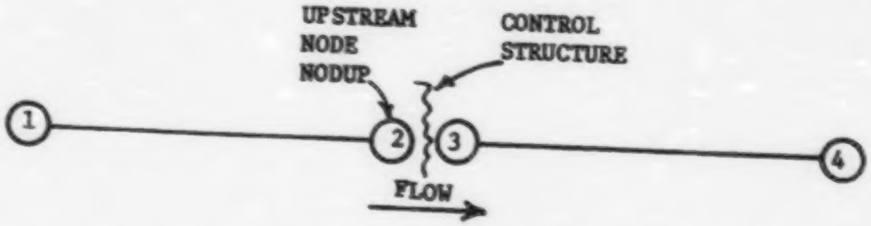
SINUSOIDAL BOUNDARY CONDITION

BOUNDARY NODE CONDITIONS, NOBC(KN) = 5

This card is supplied only when NOBC(KN) = 5.

NODUP							
I 10							
10	20	30	40	50	60	70	80

NODUP - the number of the node on the upstream side of the control structure. The discharge of the downstream node is taken from that of the upstream node. There are four cases: (1) the upstream node has discharge, Q, specified. In this case, the program takes this value directly. (2) the upstream node is a Z versus Q, or rating curve type boundary. In this case, the program sets the discharge of the downstream node equal to that determined by the program for the upstream node at the end of the previous time step. (3) the upstream node is a stage-routing type boundary. The discharge is handled as in Case 2. (4) the upstream node is of the Z-specified type. The discharge is handled as in Case 2.



CARD F-d

5.8 CARD GROUP G

HYDRAULIC OUTPUT PARAMETERS

CARD	TYPE
a	Identity Card
b	Number of Hydrographs
c	Hydrograph Parameters
d	Number of Hydraulic Profiles
e	Profile Parameters

NOTE: Card Group G must be omitted if the hydraulic calculations, IOPT(1) = 2, are not executed, that is when the hydraulic solution is read from tape (IOPT(5) = 1).

If IOPT(2) = 2, this card group must be repeated as many times as there are periods.

CARD G-a

IDENTITY CARD							
HYDRAULIC OUTPUT PARAMETERS							
FORMAT (20A4)							
10	20	30	40	50	60	70	80

NHYD = number of hydrographs requested

CARD
G-b

NUMBER OF HYDROGRAPHS (VARIABLE VS. TIME)

Cards G-b and G-c constitute a package, however, if the user does not wish to see the hydrographs it is not necessary to include card G-c.

NHYD							
I 10							
10	20	30	40	50	60	70	80

NHYD = number of hydrographs requested

HYDROGRAPH PARAMETERS

Card G-c must be repeated for the number of hydrographs, NHYD, requested.

KHYD(IH)	XHYD(IH)	IHPER					
I 10	F 10.5	I 10					
	ft.						
10	20	30	40	50	60	70	80

KHYD(IH) = reach in which hydrograph IH is to be produced.

XHYD(IH) = desired location inthe reach for the hydrograph. The program will find the nearest computational mesh point to this location and produce the hydrograph there. (No interpolation).

IHPER = period over which the desired hydrograph is to be produced. When IOPT(2) = 1, IHPER = 1. In a transient solution, this value should be the number of the current period. The retrieval system is awkward; however, it is felt that comprehensive output is best obtained by storing the solution on tape or disk, and searching it later. Output can then be produced graphically as in the plotting program.

CARD G-c

CARD G-d

NUMBER OF HYDRAULIC PROFILES (VARIABLE VS DISTANCE)

Cards G-d and G-e constitute a package; if the user does not wish to see the hydraulic profiles it is not necessary to include card G-e.

NPRO							
I 10							
10	20	30	40	50	60	70	80

NPRO = number of hydraulic profiles requested.

CARD G-e

PROFILE PARAMETERS

Card G-e must be repeated for the number of hydraulic profiles, NPRO, requested.

KPRO(IPHY)	INCHY(IPHY)	IPPER(IPHY)					
I 10	I 10	I 10					
10	20	30	40	50	60	70	80

KPRO(IPHY) = reach in which profile IPHY is to be printed

INCHY(IPHY) = time increment at which profile IPHY is to be printed, refer to card A-e for total number of increments, NINC.

IPPER(IPHY) = period in which profile IPHY is to be printed, refer to card G-c for further definition IHPER.

These profiles must be specified consecutively with time.

5.9 CARD GROUP H

WATER QUALITY BOUNDARY CONDITIONS AT THE NODES

CARD	TYPE
a	Identity Card for Water Quality Boundary Conditions
b	Water Quality Node Parameters
c	Constant or Variable Boundary Conditions
d	Time Constant Card for Ocean Boundary Conditions
e	Water Quality Constituent Card for Ocean Boundary Conditions

NOTE: Card Group H must be omitted if the water quality computations are deleted, JOPT(1) = 2.

If JOPT(2) = 2, this card group must be repeated as many times as there are periods.

CARD H-a

IDENTITY CARD FOR WATER QUALITY BOUNDARY CONDITIONS							
WATER QUALITY BOUNDARY CONDITIONS							
FORMAT (20A4)							
10	20	30	40	50	60	70	80

WATER QUALITY NODE PARAMETERS

For interior nodes, or control structure nodes, no other cards are required and the computer skips to the next Node Parameter Card. However, for boundary nodes there are two classes, one for constant or variable boundary conditions (Card H-c) and a second for ocean boundaries (Cards H-d and H-e).

KN	NOBCM(KN)	IBCM(KN)	ITXM(KN)				
I 10	I 10	I 10	I 10				
10	20	30	40	50	60	70	80

KN = number of the node for the following information

NOBCM(KN) = indicates the type of boundary condition to be applied at node KN
= 0, junction or interior node
= 1, concentration specified
= 2, dispersive flux specified
= 3, total flux specified
= 4, ocean boundary condition
= 5, control structure node (up or downstream)

IBCM(KN) = indicates the time dependence of the boundary condition at node KN
= 1, constant with time
= 2, variable with time

ITXM(KN) = number of table entries per parameter modeled for the boundary condition specifications. For constant boundary conditions, or the ocean boundary condition, only one card per parameter modeled is required. Variable boundary conditions will require additional table entries.

CARD H-b

CONSTANT OR VARIABLE BOUNDARY CONDITIONS

Card H-c must be repeated for each quality constituent specified on Card A-d, the Water Quality Parameter Options. For variable boundary conditions and for each quality constituent, a package of cards corresponding the time varying input must be supplied. If Card H-c is supplied then Cards H-d, H-e are not to be supplied.

SYM(L)		TIM(KN,J)	CNODE	DFNODE	TFNODE			
A4	6X	F 10.5	F 10.5	F 10.5	F 10.5			
		Sec.						
	10	20	30	40	50	60	70	80

SYM(L) = the symbolic (one to four letter) name of the water quality parameter being specified. Use sequence of Table 5.2.

TIM(KN,J) = prototype time referred to the beginning of the period for the table entry. This may be omitted if the boundary condition is constant, IBCM(KN) = 1.

CNODE = specified concentration of the water quality parameter.

DFNODE = specified dispersive flux of the water quality parameter.

TFNODE = specified total flux of the water quality parameter.

Units are (for flux):

for temperature:	BTU/day
for coliforms:	No/hour
for all others:	lbs/day - Nitrogen

NOTE: For total of dispersive flux, quantity for parameter dissolved oxygen should be in terms of DOD (Dissolved O_2 Defecit).

CARD H-c

TIME CONSTANT CARD FOR OCEAN BOUNDARY CONDITIONS

If an ocean boundary NOBCM(KN) = 4 is specified then 2 to 5 cards are required, the time constant card, and quality constituent card H-e for each constituent modeled.

TCON(KN)							
F 10.5							
10	20	30	40	50	60	70	80

TCON(KN) = time constant for decay of the concentration difference CO(KN) − CS(KN) at the ocean boundary node, where CO(KN) is the concentration leaving the estuary on ebb flow and CS(KN) is specified on the next card. The boundary concentration is specified by:

$\mathrm{CONC(KN)} = \mathrm{CS(KN)} + (\mathrm{CO(KN)} - \mathrm{CS(KN)}) \cdot e^{(-\mathrm{TCON(KN)} \cdot t)}$
where t = (time − time that flood began)
and where $\mathrm{TCON(KN)} \cdot t < 88$
$\mathrm{CONC(KN)} = \mathrm{CS(KN)}$ when $\mathrm{TCON(KN)} \cdot t \geq 88$

CARD H-e

WATER QUALITY CONSTITUENT CARD FOR OCEAN BOUNDARY CONDITIONS

If an ocean boundary NOBCM(KN) = 4, is specified then this card must be repeated for each quality constituent specified on card A-d, the Water Quality Parameter Options.

SYM(L)	CS(KN,L)						
A4,6X	F 10.2						
	ppm						
10	20	30	40	50	60	70	80

SYM(L) = The symbolic (one to four letter) name of the water quality parameter being specified. Use sequence of Table 5.2.

CS(KN,L) = concentration of the water quality parameter of the incoming ocean water on flood at the ocean boundary node.

5.10 CARD GROUP I

WATER QUALITY OUTPUT PARAMETERS

CARD	TYPE
a	Identity Card
b	Number of Quality Graphs
c	Water Quality Graph Parameters
d	Number of Water Quality Profiles
e	Water Quality Profile Parameters

NOTE: Card Group I must be omitted if the water quality computations are deleted, JOPT(1) = 2.

If JOPT(2) = 2, this card group must be repeated as many times as there are periods.

IDENTITY CARD							
WATER QUALITY GRAPHS AND PROFILE OUTPUT PARAMETERS							
FORMAT (20A4)							
10	20	30	40	50	60	70	80

CARD I-a

CARD I-b

NUMBER OF QUALITY GRAPHS (VARIABLE VS TIME) Cards I-b and I-c constitute a package, however, if the user does not wish to see the hydrographs it is not necessary to include card I-b.							
NPOL							
I 10							
10	20	30	40	50	60	70	80

NPOL = number of quality graphs requested

WATER QUALITY GRAPH PARAMETERS							
KPOL(IC)	XPOL(IC)	MCPER					
I 10	F 10.5	I 10					
	ft.						
10	20	30	40	50	60	70	80

KPOL(IC) = reach in which quality graph IC is to be produced

XPOL(IC) = desired location in the reach for the quality graphs. The program will find the nearest computational mesh point to this location, and produce the quality graph there.

MCPER = period over which the desired quality graph is to be produced. The remarks made in Card Group G about hydrographs apply here, also. At a given location over several periods, it must be split into individual quality graphs covering single periods.

CARD I-c

CARD I-d

NUMBER OF WATER QUALITY PROFILES (VARIABLE VS DISTANCE)

Cards I-d and I-e constitute a package, however, if the user does not wish to see the quality profiles it is not necessary to include card I-d.

NMPRO							
I 10							
10	20	30	40	50	60	70	80

NMPRO = number of concentration profiles requested

CARD I-e

WATER QUALITY PROFILE PARAMETERS

Card I-e must be repeated for the number of quality prfiles, NMPRO, requested.

MPRO(IPWQ)	INCWQ(IPWQ)	MPPER(IPWQ)					
I 10	I 10	I 10					
10	20	30	40	50	60	70	80

MPRO(IPWQ) = reach in which profile IPWQ is to be printed

INCWQ(IPWQ) = water quality time increment at which profile IPWQ is to be printed

MPPER(IPWQ) = water quality in which profile IPWQ is to be printed

The profile must be specified consecutively with time.

VI. MODEL APPLICATION - TEST CASES

The following is a discussion of the application of the real-time nitrogen-cycle model in a hypothetical waterway simulated for demonstration in this manual. The objective of this effort was to demonstrate the coupling of the transport processes in an advective system with the biogeochemical nitrogen transformation processes.

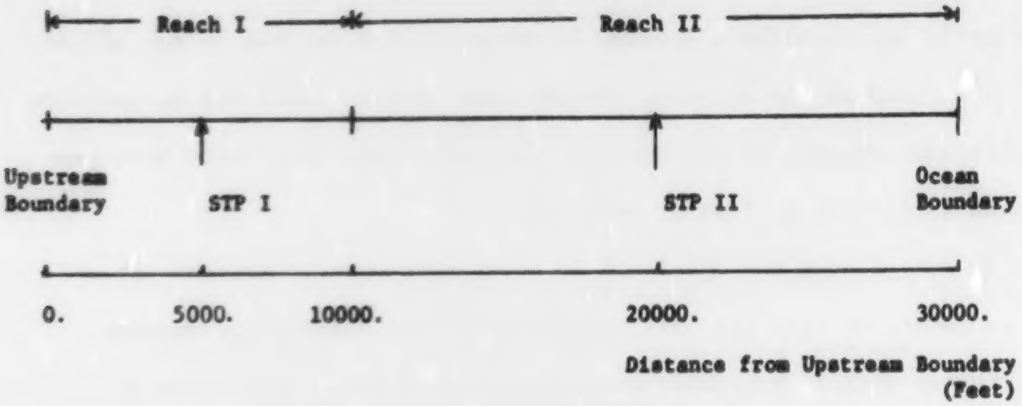
6.1 Description of the Estuary Test Case

The estuary is assumed to have a length of 30,000 ft (9,146 m) and a width of 1000 ft (305 m), and is characterized by a Manning roughness coefficient of 0.018 and a slope of 0.00001. A constant fresh water inflow rate of 1000 cfs (28 m^3/sec) enters at the head of tide. The salinity at the ocean end of the estuary is 15,000 ppm and the ocean tidal range is 4 ft (1.2 m) about an average water surface elevation of 15 ft (4.6 m). Two sewage treatment plants (STP)discharge to the estuary and are located as shown in Figure 6.1. The flow from STP I is 10 mgd (38,000 m^3/day) and that from STP II is 20 mgd. (76,000 m^3/day). The waste from these plants are as described in Figure 6.1. The analysis was performed in several successive steps.

6.2 Hydraulic Solution For Real-Time Estuary Analysis

The first step was to determine the quasi-steady state hydraulic response of the Estuary. The term quasi-steady state refers to the characteristic whereby the same hydrodynamic profile is repeated each tidal period. This is possible only in cases where the hydraulic upstream and lateral inflows are constant and the tidal range at the mouth of the estuary is repeated from one tidal period to the next. This obviously applied in the case at hand. Thus, the hydraulic solution is transient within a particular tidal period, but steady state when corresponding time are compared in different tidal periods. The treatment plant discharges are considered passive injections, that is they do not affect the flow field in the estuary. If the flow rate of these discharges were significant compared to the estuary flow rate, then they could have been treated as lateral inflows of zero width.

In determining the quasi-steady state hydrodynamic response it was necessary to simulate only the hydraulic and salinity parameters. Other water quality variables were not required for this portion of the analysis. The salinity parameter is required because it appears in the conservation of momentum equation. Initial conditions were assumed for the hydraulic parameters (surface elevation and discharge) and for the salinity profile. The boundary conditions and geometry were prescribed as outlined above. The program was run for several tidal periods until the quasi-steady state response was obtained. (Note that the choice of initial conditions affects only the number of tidal periods needed to achieve the quasi-steady state response. Regardless of the choice of initial conditions, the quasi-steady state response should always be the same.)


Reach I
Reach II
Upstream Boundary
STP I
STP II
Ocean Boundary
0.
5000.
10000.
20000.
30000.
Distance from Upstream Boundary (Feet)

Description of Waste Injections

	STP I		STP II	
	Conc. (ppm)	Load (lb/day)	Conc.(ppm)	Load (lb/day)
NH3-N	20	1668.	20	3336.
NO3-N	2	167.	2	334.
PON	10	834.	10	1668.
DON	10	834.	10	1668.

FIGURE 6.1 SCHEMATIC OF ESTUARY AND TREATMENT PLANT LOADINGS

The next step was to store the hydrodynamic profile on a computer tape to be used in later runs involving water quality variables. In this way, it would not be necessary to recompute the hydraulic solution in these later runs. The hydraulic solution was now computed again, but this time for one period only and stored on computer tape. The initial conditions for this run were determined from the quasi-steady state response determined above thereby assuring that the one tidal period now being stored on tape would give the same response, The input data for this run is given in Appendix I.a. A portion of the output is shown in Appendix I.b.

6.3 Water Quality Solution For Real-Time Estuary Analysis

The next step involved determining the quasi-steady state response for water quality parameters. The input data for this run is listed in Appendix I.c. Note that the hydraulic solution was not executed but read from tape for this simulation. Boundary conditions were specified, and initial conditions assumed for all water quality parameters of interest for this run. (Not all of the parameters that the model is capable of simulating were run). The program was run for ten tidal periods which proved adequate for determining the quasi-steady state response. The number of periods required would vary depending upon the accuracy of the assumed initial conditions as compared with the true response. A portion of the output is shown in Appendix I.d.

6.4 Hydraulic and Water Quality Solutions for River Analysis

For the River Test Case, the channel geometry chosen was identical to that for the Estuary discussed above. Therefore, the ocean boundary condition was not stipulated. Instead, a discharge is prescribed at the downstream end, the value of which is equivalent to the discharge into the River from upstream sources. In the case of a fully steady-state hydraulic system (as in this river case), the program computes the steady-state hydraulic solution initially and then uses this solution for the specified duration in the water quality computations. Thus, it is not necessary to compute the steady state hydraulic solution separately and store it on tape as with real-time estuary analysis. The calculations are performed in the same computer run. The input data for this is shown in Appendix II.a and a portion of the output is shown in Appendix II.b. The steady-state river system requires that only one period be specified but the duration of that period can be as long as desired and is not the same as a tidal period in the real-time unsteady flow case. Although the hydraulic solution is steady state in this River analysis, the water quality solution is transient and the length of the period must be chosen such that the steady state water quality response will be determined. For the case at hand and for the initial conditions specified, a period of 357,120 seconds was required.

6.5 Plotting of Hydraulic and Water Quality Solutions

The hydraulic and water quality solutions from the Estuary analysis and the water quality solution from the River analysis in the above runs were stored on a sequential data set computer tape. The user is then able to obtain graphic results of these solutions by selecting output information in accordance with the plotting program discussed in Chapter VII.

6.6 Discussion of Test Case Simulation

Figure 6.2 shows the tidal discharge as a function of time throughout one tidal cycle at the ocean end, X = 30,000 ft (9150 m) and at section

X = 10,000 ft (3049 m) for the Estuary. The maximum tidal discharge at the ocean end is 9500 cfm (270 m^3/s) and corresponds to a maximum tidal velocity of 0.65 ft/s (0.2m/s). This may be compared with the River case which is characterized by a constant discharge rate of 1000 cfs (28.3 m^3/s) and a constant velocity of 0.07 ft/s (0.02 m/s).

Instantaneous longitudinal distributions of salinity in Reach II at four times during a tidal period are shown in Figure 6.3. The time T/4 corresponds to high water slack and 3 T/4 to low water slack. Since the longitudinal dispersion coefficient is assumed to be proportional to the local longitudinal salinity gradient in accordance with Equation (3.4) the dispersion coefficient increases significantly within the salinity intrusion region. In the non-saline region the dispersion coefficient is related to the local tidal velocity by a modified Taylor dispersion relation. For this study, the value of K in Equation (3.4) was 50 ft^2/s (4.6 m^2/s). The longitudinal dispersion coefficient then has an average value of 15 ft^2/s (1.5 m^2/s) in the non-saline portion and reaches a maximum value of about 400 ft^2/s (37 m^2/s) in the salinity intrusion region.

Figure 6.4 shows instantaneous longitudinal profiles of ammonia-nitrogen at four times in a tidal period. The large peaks of concentration adjacent to the upstream waste treatment plant in Reach I are due to the combined effect of low tidal velocities near the head of tide and low dispersion. The flushing effect near the ocean boundary is indicated by the large differences in ammonia concentration between high water slack (T/4) and low water slack (3 T/4).

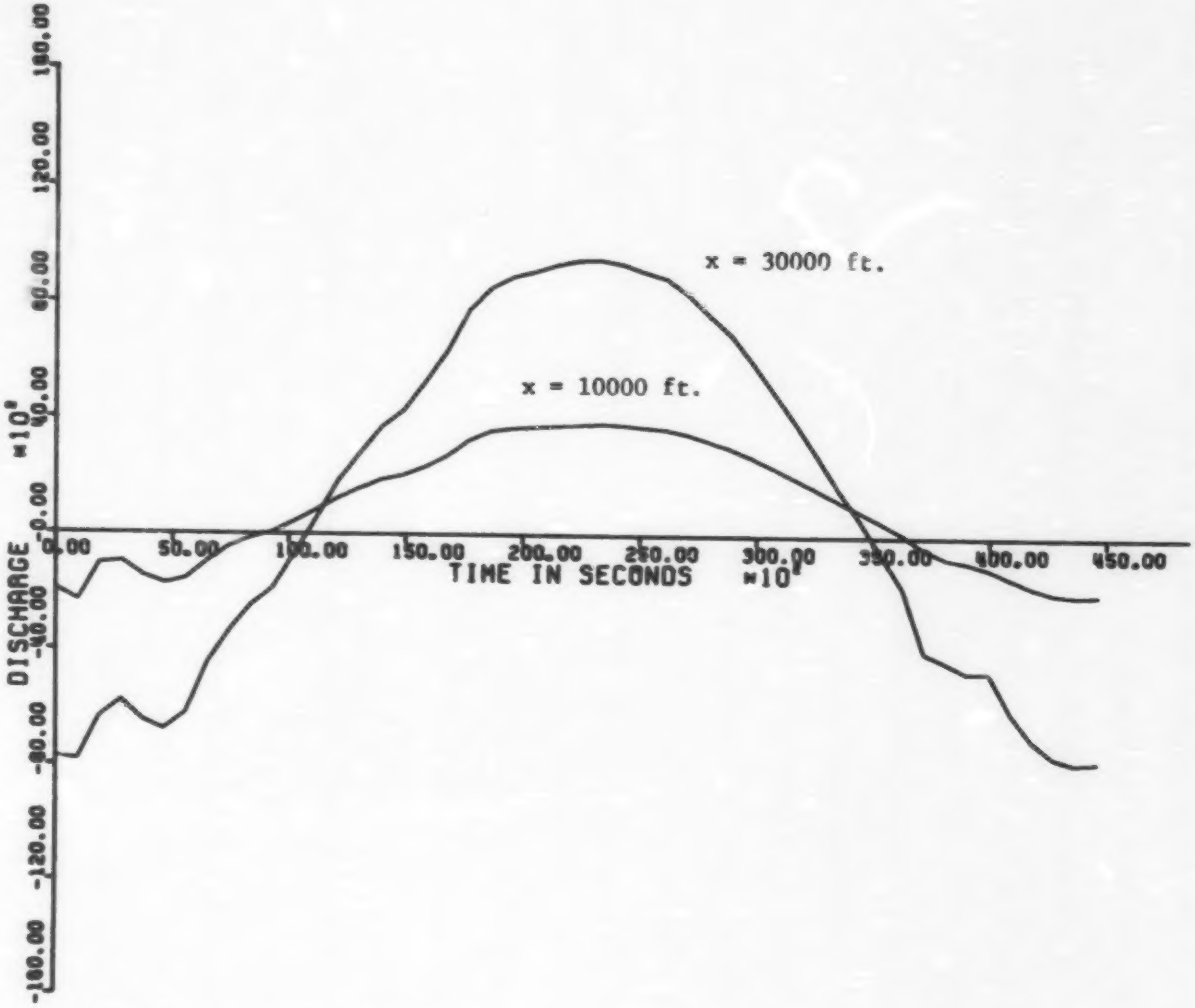


FIGURE 6.2 TIDAL DISCHARGE vs TIME AT x = 10000 ft. and x = 30000 ft. IN ESTUARY

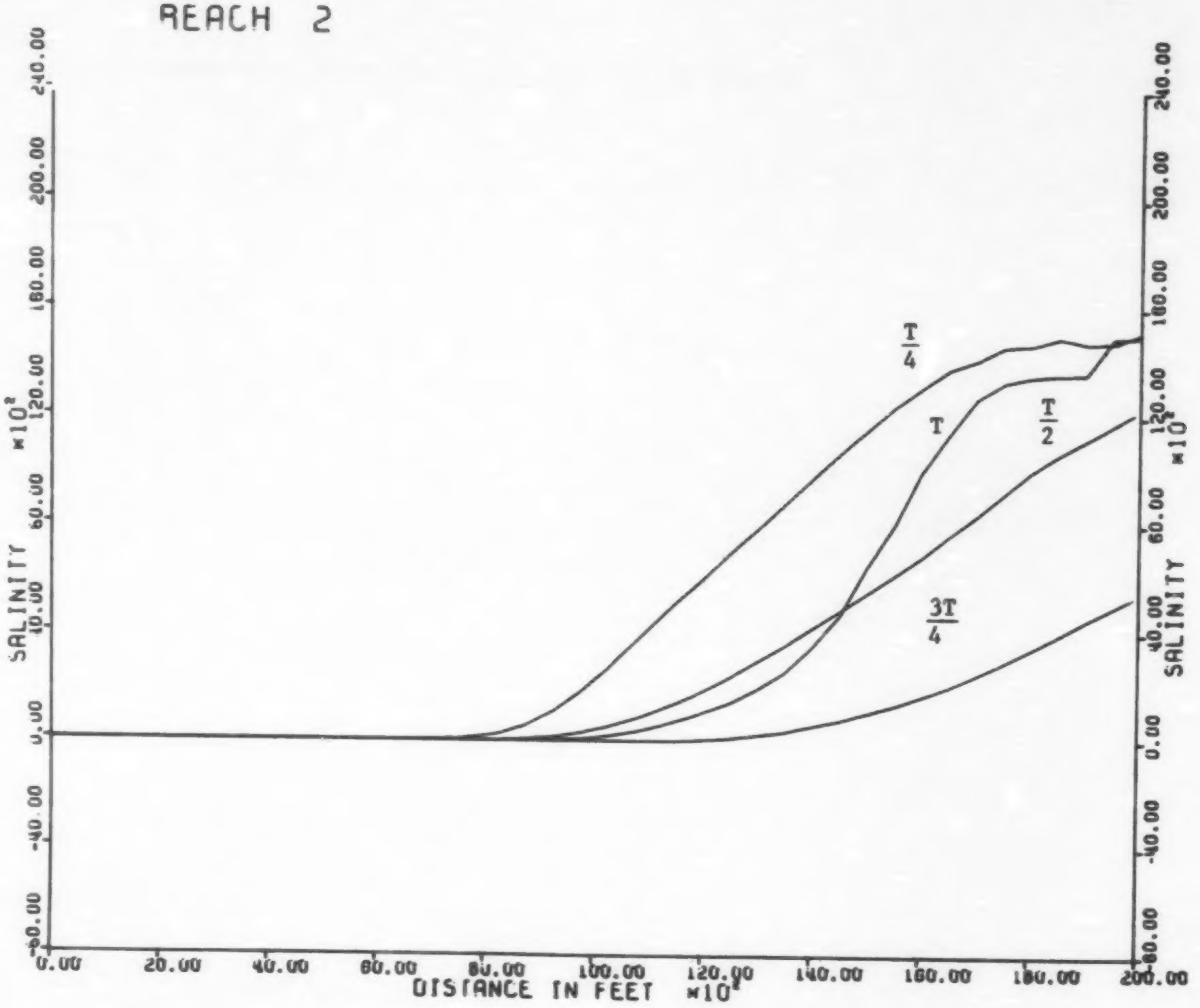


FIGURE 6.3 SALINITY PROFILES IN REACH II OF ESTUARY

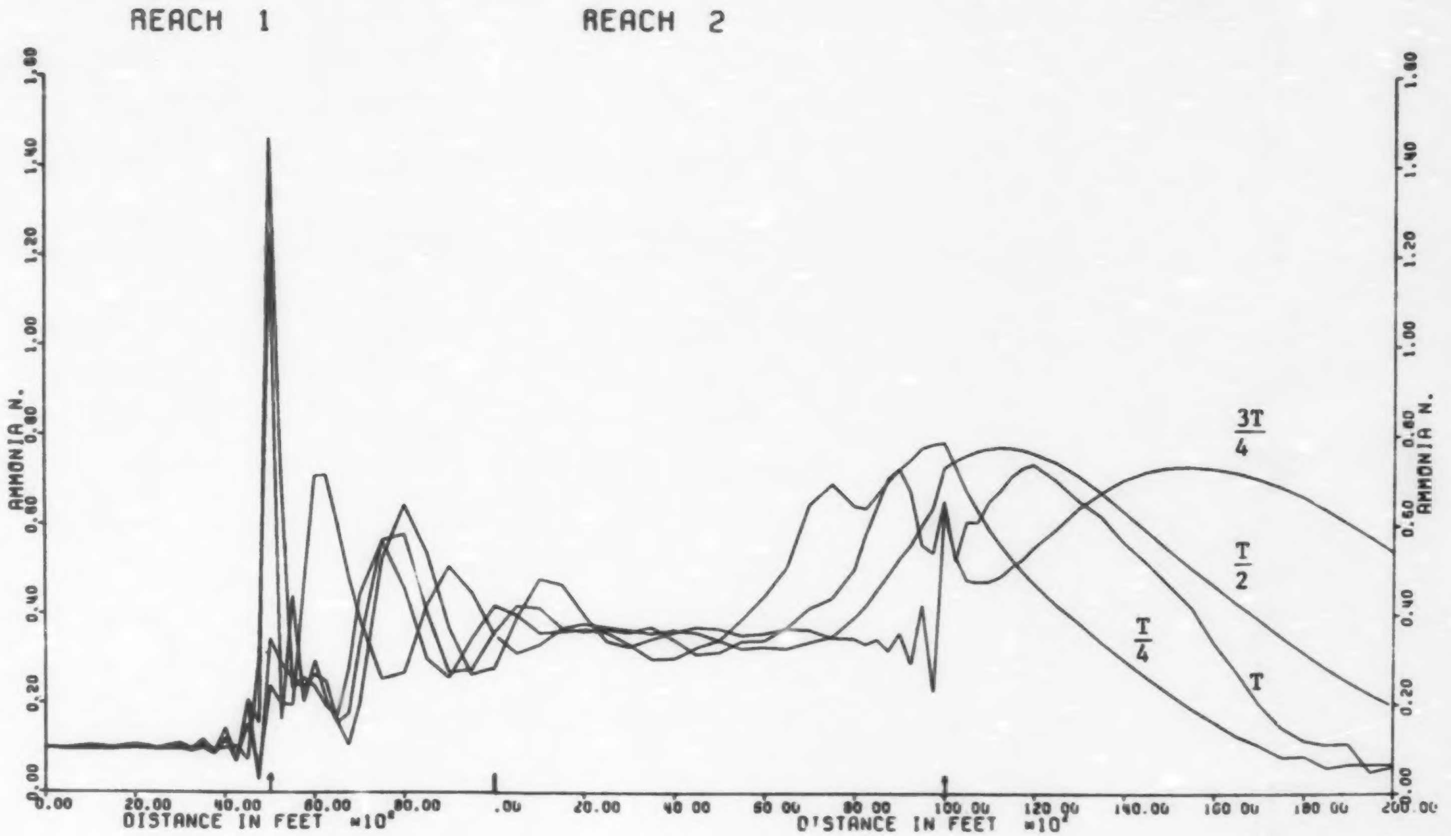


FIGURE 6.4 AMMONIA-N CONCENTRATIONS IN ESTUARY

Figure 6.5 shows the predicted ammonia concentrations for the River case. A constant dispersion coefficient equal to 65 ft^2/s (6 m^2/s) was used for this simulation.

Similar profiles are shown for nitrate and particulate organic nitrogen in Figures 6.6 - 6.9.

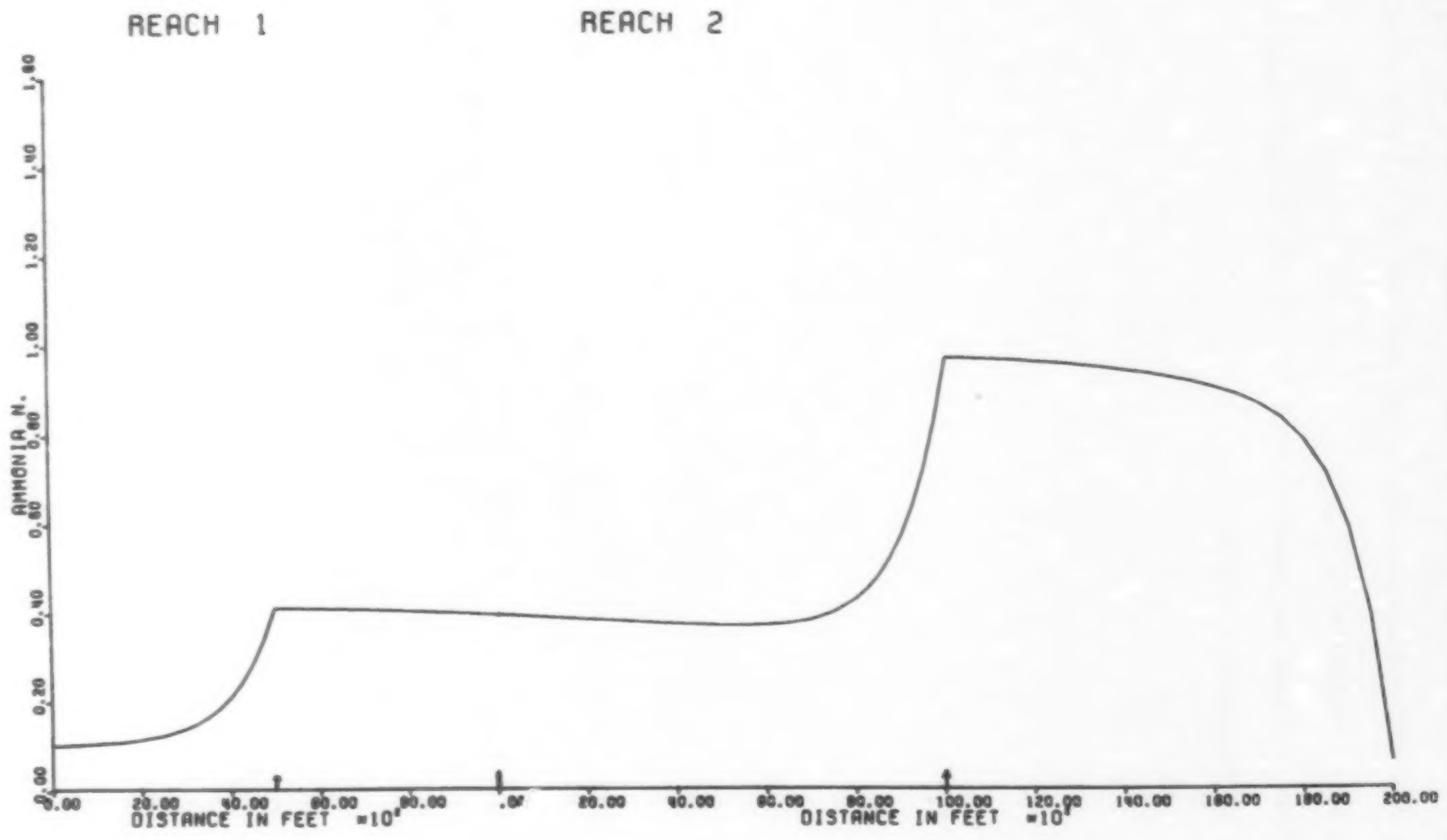


FIGURE 6.5 AMMONIA-N CONCENTRATIONS IN RIVER

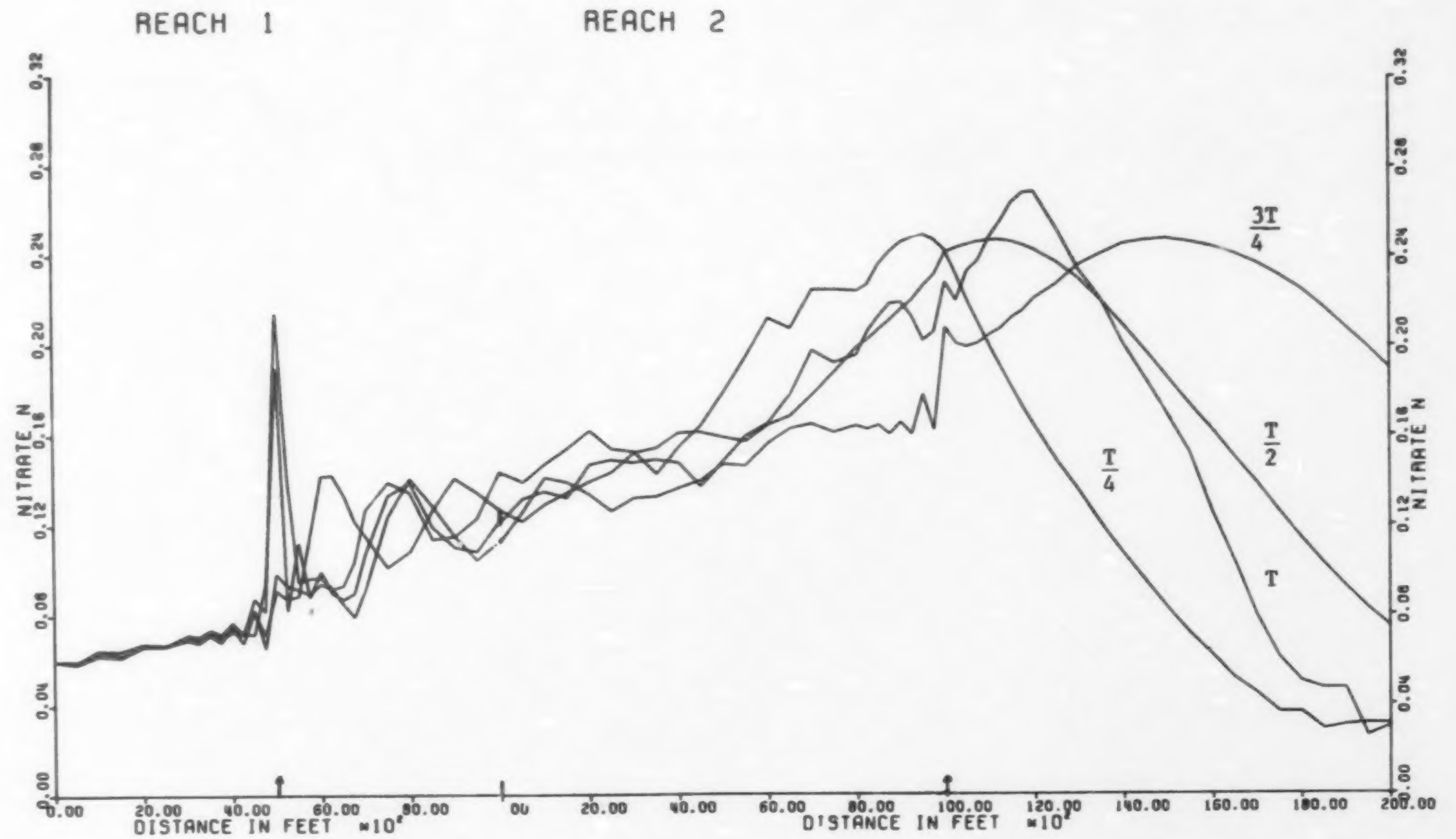


FIGURE 6.6 NITRATE-N CONCENTRATIONS IN ESTUARY

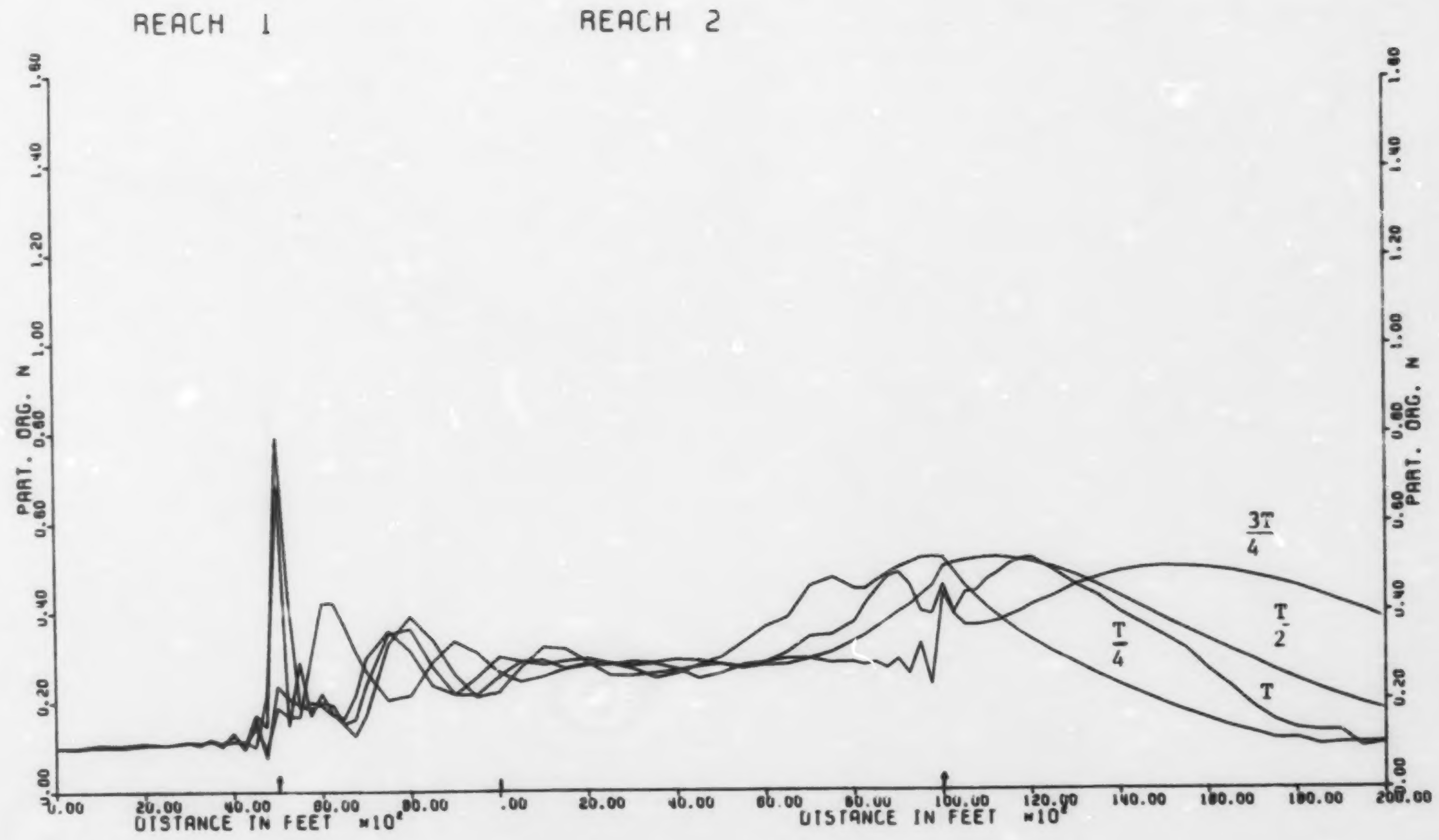


FIGURE 6.7 PARTICULATE ORGANIC-N CONCENTRATIONS IN ESTUARY

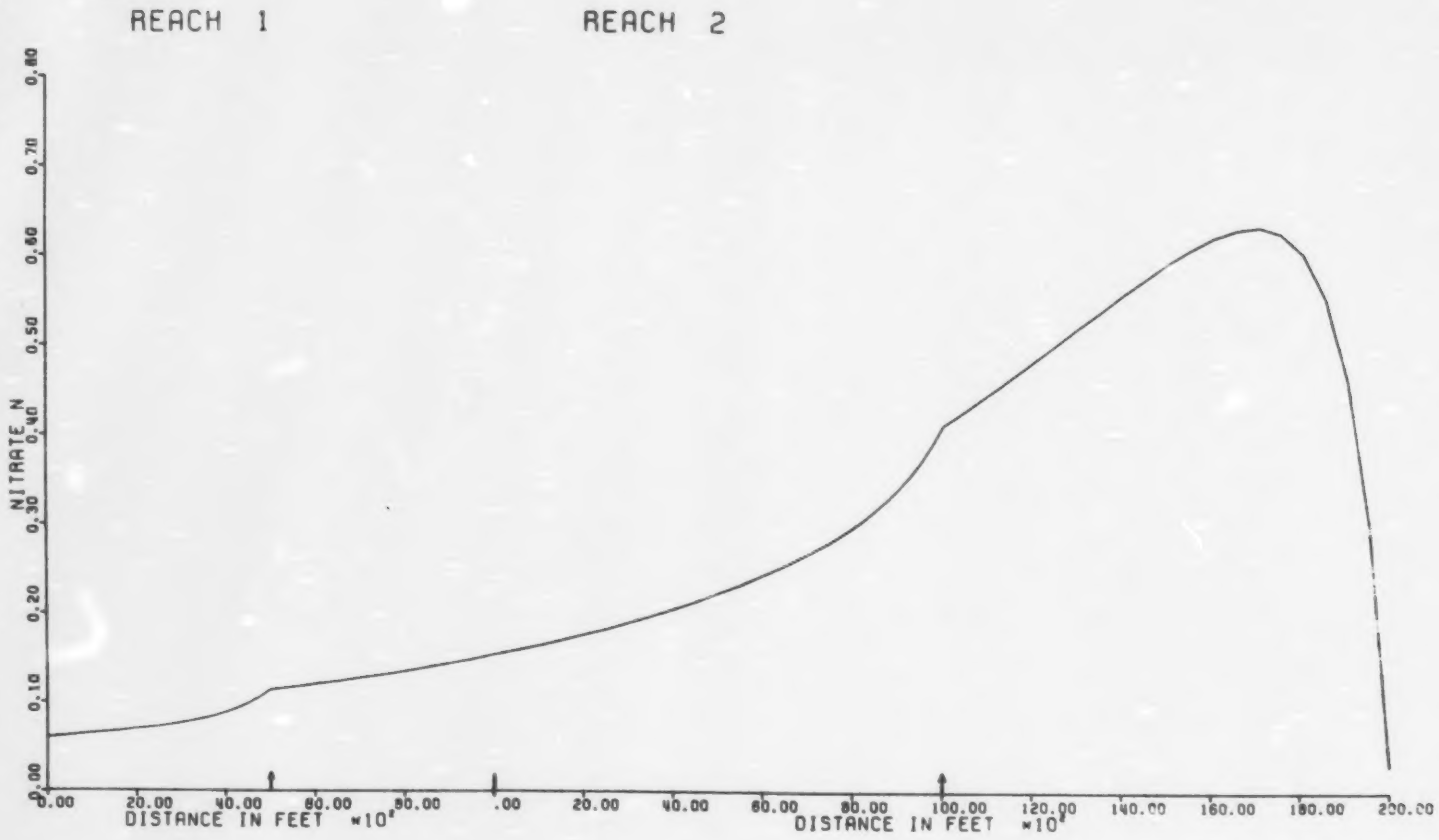


FIGURE 6.8 NITRATE-N CONCENTRATIONS IN RIVER

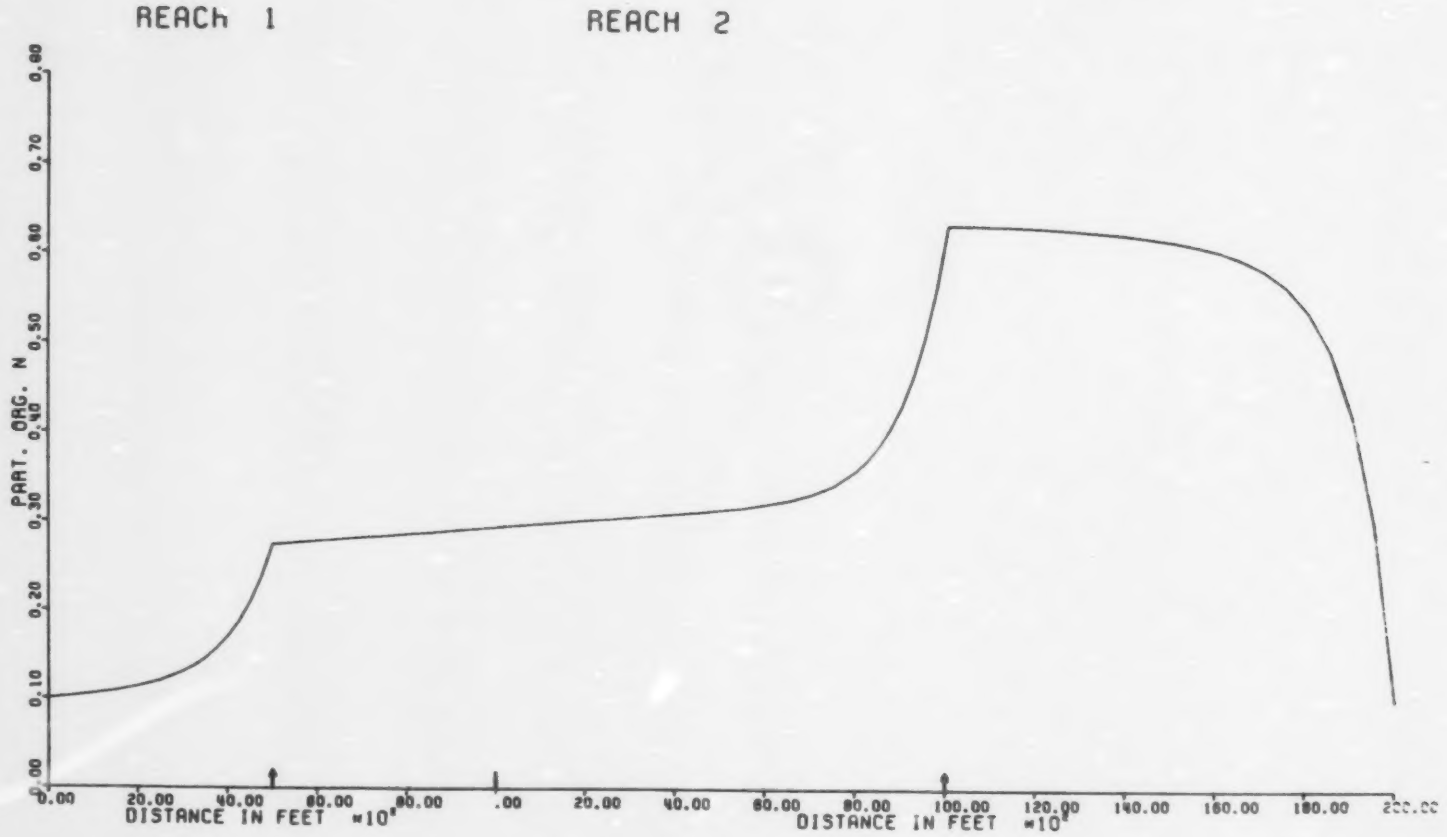


FIGURE 6.9 PARTICULATE ORGANIC-N CONCENTRATIONS IN RIVER

VII. PLOTTING PROGRAM

7.1 Description of the Plotting Program

The large volume of numerical information generated by the computer program is conveniently representable in graphic form. A plotting program is available for use on an incremental drum plotter. The program is in FORTRAN and uses the standard set of plotting commands as described by California Computer Products, Inc. 1970.

In order to utilize the plotting feature the user must have specified the option in the Network Model that creates a sequential data set of the calculated dependent variables. There are two such datasets possible, one for hydraulics, the other for water quality concentrations. Two types of plots are possible.

(1) Dependent variable vs. distance at a specific time.

(2) Dependent variable vs. time at a specific location

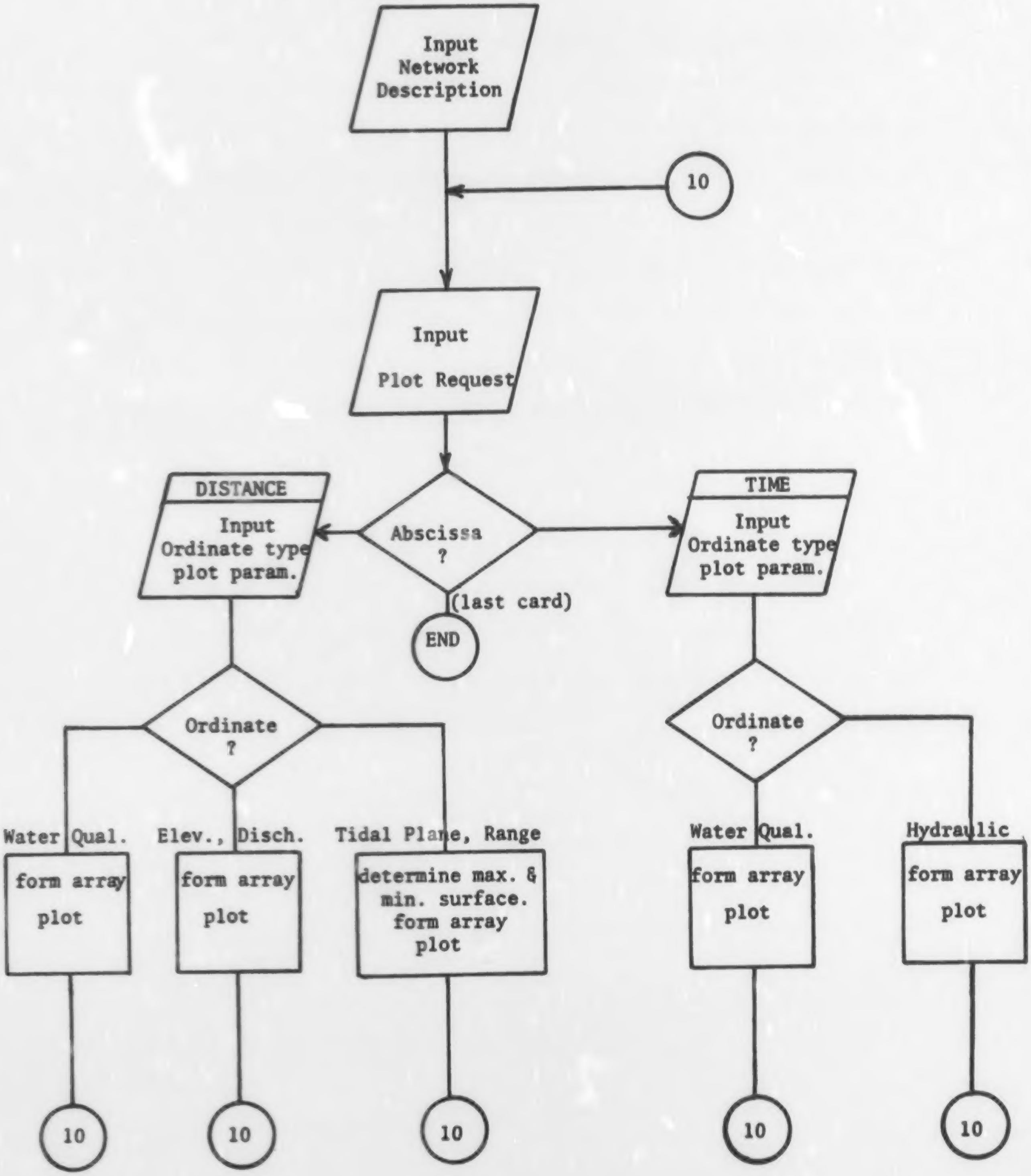
Special features permit the user to plot several variables on the same frame & also to plot user supplied data points as special symbols.

The general functioning of the program is illustrated in Figure 7.1

7.2 Input Data Preparation

Pages 157 through 165 describe the input data required to use the plotting program. To facilitate preparation of input data the user should refer to the output listing of the network model run that produced the plotting datasets.

FIGURE 7.1 GENERALIZED FLOW CHART: PLOTTING PROGRAM


Input
Network
Description
10
Input
Plot Request
Abscissa
?
(last card)
END
DISTANCE
Input
Ordinate type
plot param.
TIME
Input
Ordinate type
plot param.
Ordinate
?
Ordinate
?
Water Qual.
form array
plot
Elev., Disch.
form array
plot
Tidal Plane, Range
determine max. &
min. surface.
form array
plot
Water Qual.
form array
plot
Hydraulic
form array
plot
10
10
10
10
10

PLOT -1

PLOT IDENTIFICATION							
ID							
A8							
10	20	30	40	50	60	70	80

ID = one to eight character identification of the plot.

This will be plotted at the bottom of each frame as well as being printed on the output listing.

PLOT - 2

TIME PARAMETERS							
NPER	NINC	RATIO	DT				
I 10	I 10	F 10.0	F 10.0				
10	20	30	40	50	60	70	80

NPER = number of tidal periods. (1 in the case of river flow).

NINC = number of hydraulic time increments within each tidal period.

RATIO = ratio of water quality time increment to hydraulic time increment.

DT = actual measure of hydraulic time increment.

PLOT - 3

NUMBER OF REACHES							
NREACH							
I 10							
10	20	30	40	50	60	70	80

NREACH = number of reaches

REACH PARAMETER CARDS (ONE CARD FOR EACH REACH)

(In same sequence as that given by reach - node connectivity table)

K	NSN(K)	MESHPT(K)					
I 10	I 10	I 10					
10	20	30	40	50	60	70	80

K = the numerical identification of the reach

NSN(K) = number of hydraulic mesh points in reach K

MESHPT(K) = number of water quality mesh points in reach K

For NSN(K) and MESHPT(K) consult output listing for a particular run as these are the number of computational mesh points, not the number of user-supplied cross-sections.

PLOT 4

PLOT 5-d
(vs distance)

PLOT SELECTION VS. DISTANCE (FOR PLOTS VS. TIME USE CARD PLOT-5-t)

	D	PER	T	PL	YMIN	YMAX	NPTS	
9X	A1	I 10	I 10	F 10.0	F 10.0	F 10.0	I 10	
		seconds		in.				
	10	20	30	40	50	60	70	80

D = letter "D" in column 10

PER = tidal period of profile

T = increment within PER of profile
(not applicable for tidal range or high and
low water planes) Use hydraulic increment for hydraulic variables
and water quality increment for water quality variables.

PL = plot length (X-axis in inches)

YMIN = minimum value of Y-axis

YMAX = maximum value of Y-axis

NPTS = number of individual points to be plotted.
(if ≠ 0 supply cards PLOT - 7 after PLOT - 6-d)

PARAMETER SELECTION CARD

SYMB	REACH	S1	S2	DX	MULTI		
A4,6X	I 10	I 10	I 10	F 10.0	I 10		
10	20	30	40	50	60	70	80

SYMB = S(Salinity, T(Temperature), CBOD(Carbonaceous Biochemical Oxygen Demand), NH3(Ammonia Nitrogen), NO2(Nitrite Nitrogen), MO3(Nitrate Nitrogen), PHYN(Phytoplankton Nitrogen), ZOON(Zooplankton Nitrogen), PON(Particulate Organic Nitrogen), DON(Dissolved Organic Nitrogen), DO(Dissolved Nitrogen), FCOL(Fecal Coliform), Z(Elevation), Q(Discharge)

REACH = reach number

S1 = starting mesh point number

S2 = ending mesh point number

DX = increment length between sections (feet) (hydraulics only)

MULTI = 0 or blank, a single variable is being plotted
1, this variable plotted with others (same frame)
9, this is the last of several variables being plotted together

NOTE: When MULTI $\neq$ 0 corresponding card 5-d is needed for each variable being plotted.

PLOT 5-t
(vs time)

PLOT SELECTION VS TIME (FOR PLOTS VS DISTANCE USE CARD PLOT 5-d)

	T	REACH	XDIST	PL	YMIN	YMAX	NPTS	
9X	A1	I 10	F 10.0	F 10.0	F 10.0	F 10.0	F 10.0	
			ft	in				
	10	20	30	40	50	60	70	80

T = the letter "T" in column 10

REACH = the reach number (an integer)

XDIST = distance of the point of interest from the upstream end.
(Program will take closest computational section).

PL = plot length (X - axis)

YMIN = minimum value for Y axis

YMAX = maximum value for Y axis

NPTS = no. of individual points to be plotted.
(if ≠ 0 supply cards PLOT - 7 after plot 6-t)

PARAMETER SELECTION CARD

SYMB	PER1	T1	PER2	T2	DX	MULTI	
A4,6X	I 10	I 10	I 10	I 10	F 10.0	I 10	
		seconds		seconds	feet		
10	20	30	40	50	60	70	80

SYMB = S(Salinity), T(Temperature), CBOD(Carbonaceous Biochemical Oxygen Demand), NH3(Ammonia Nitrogen), NO2(Nitrite Nitrogen), NO3(Nitrate Nitrogen), PHYN(Phytoplankton Nitrogen), ZOON(Zooplankton Nitrogen), PON(Particulate Organic Nitrogen), DON(Dissolved Organic Nitrogen), DO(Dissolved Oxygen), FCOL(Fecal Coliform), Z(Elevation), Q(Discharge)

PER1 = tidal period at start

T1 = increment within tidal period at start: the first increment of 1st period is 0, all other periods it is 1.

PER2 = tidal period at finish

T2 = increment within tidal period at finish (for a river, the maximum time increment = number of increments - 1)

DX = increment length between sections if constant (hydraulics only)

MULTI = 0 or blank, a single variable is being plotted
1, this variable plotted with others (same frame)
9, this is the last of several variables being plotted together

NOTE: when MULTI = 0 corresponding card 5 -t is needed for each variable being plotted

PLOT 6-t

INDIVIDUAL DATA POINT CARDS (Only if NPTS ≠ 0 on Card Plot 5-t or Plot 5-d)

One card per point
These cards follow Card Plot 6

X	Y	NUSER					
F 10.0	F 10.0	I 10					
feet or seconds							
10	20	30	40	50	60	70	80

X = abscissa. time in seconds from the beginning of the plot (PER1, T1) or distance in feet from beginning (S1).

Y = ordinate value

NUSER = Integer Code corresponding to the geometric point being plotted. If not defined the previously defined value will be used. If no value is given a default of 11 will be taken which is an asterisk(*).

PLOT 7

7.3 Example

To illustrate the use of the plotting program, on the following pages is listed the input data required to reproduce the plots (Fig. 6.2 - 6.9) shown in Chapter VI of this manual. Some editing was done to arrive at the final form shown. For example, Figure 6.4 is plotted as two separate pages by the program, one for Reach I and another for Reach II. These were then pasted together and reduced for presentation in the manual. The same was done for Figures 6.5 - 6.9.

The input data is listed in three separate tables as below.

1. Table 7.1 Input data for plotting hydraulic variables in the Estuary = Figure 6.2.

2. Table 7.2 Input data for plotting water quality variables in the Estuary = Figures 6.3, 6.4, 6.6, 6.7.

3. Table 7.3 Input data for plotting water quality variables in the River = Figures 6.5, 6.8, 6.9.

TABLE 7.1 INPUT DATA FOR PLOTTING HYDRAULIC VARIABLES IN THE ESTUARY

```
HYD.1
        1       48         3.       930.
        2
        1        5
        2        9
        T        1     10000.       10.   -10000.    10000.
Q                1                    1       48.     2500.         1
        T        2     20000.       10.   -10000.    10000.
Q                1          0         1       48      2500.         9
```

TABLE 7.2 INPUT DATA FOR PLOTTING WATER QUALITY VARIABLES IN THE ESTUARY

```
WOUAL2
          10        48        3.      930.
           2
           1         5        29
           2         9        49
           D        10         4       10.     -500.    15500.
S                    2         1        49                   1
           D        10         8       10.     -500.    15500.
S                    2         1        49                   1
           D        10        12       10.     -500.    15500.
S                    2         1        49                   1
           D        10        16       10.     -500.    15500.
S                    2         1        49                   9
           D        10         4       5.0        0.       1.6
NH3                  1         1        29                   1
           D        10         8       5.0        0.       1.6
NH3                  1         1        29                   1
           D        10        12       5.0        0.       1.6
NH3                  1         1        29                   1
           D        10        16       5.0        0.       1.6
NH3                  1         1        29                   9
           D        10         4       10.        0.       1.6
NH3                  2         1        49                   1
           D        10         8       10.        0.       1.6
NH3                  2         1        49                   1
           D        10        12       10.        0.       1.6
NH3                  2         1        49                   1
           D        10        16       10.        0.       1.6
NH3                  2         1        49                   9
           D        10         4        5.        0.       .32
NO3                  1         1        29                   1
           D        10         8        5.        0.       .32
NO3                  1         1        29                   1
           D        10        12        5.        0.       .32
NO3                  1         1        29                   1
           D        10        16        5.        0.       .32
```

TABLE 7.2 (Continued)

```
NO3                1          1          29                 9
          D       10          4         10.        0.     .32
NO3                2          1          49                 1
          D       10          8         10.        0.     .32
NO3                2          1          49                 1
          D       10         12         10.        0.     .32
NO3                2          1          49                 1
          D       10         16         10.        0.     .32
NO3                2          1          49                 9
          D       10          4          5.        0.     .96
PON                1          1          29                 1
          D       10          8          5.        0.     .96
PON                1          1          29                 1
          D       10         12          5.        0.     .96
PON                1          1          29                 1
          D       10         16          5.        0.     .96
PON                1          1          29                 9
          D       10          4         10.        0.     .96
PON                2          1          49                 1
          D       10          8         10.        0.     .96
PON                2          1          49                 1
          D       10         12         10.        0.     .96
PON                2          1          49                 1
          D       10         16         10.        0.     .96
PON                2          1          49                 9
```

TABLE 7.3   INPUT DATA FOR PLOTTING WATER QUALITY VARIABLES IN THE RIVER

```
WQUAL4
          1      384        3.       930.
          2
          1        5       29
          2        9       49
          D        1      128         5.        0.       1.6
NH3                1        1         29                   0
          D        1      128        10.        0.       1.6
NH3                2        1         49                   0
          D        1      128         5.        0.        .8
NC3                1        1         29                   0
          D        1      128        10.        0.        .8
NO3                2        1         49                   0
          D        1      128         5.        0.        .8
PON                1        1         29                   0
          D        1      128        10.        0.        .8
PON                2        1         49                   0
```

VIII. COMPUTER IMPLEMENTATION

8.1 Overlay Structure of FORTRAN Source Program

The FORTRAN Source Program consists of 47 routines. In order to conserve storage certain of these routines can be overlaid. This overlay structure is illustrated in Figure 8.1, the corresponding job control for IBM machines is given in Section 8.4.

8.2 Input/Output Devices and Unit Numbers

Input and output data sets are used for permanent and temporary storage of information. The input datasets consist of the input data itself and possibly a previously calculated hydraulic solution. Output datasets consist of the printed output as requested by the user and possible sequential datasets for the hydraulic and/or water quality solution. These dataset numbers are identified in Table 8.1.

8.3 Program to Modify Dimensions

Because of the large amounts of storage necessary for a comprehensive model such as an estuary including its tributaries, a special program and utility program have been combined in order to allow the user to modify the dimensioned arrays of the FORTRAN source program. The object of this is to permit a special compilation of the FORTRAN Source Program using dimensioned arrays that correspond to the needs of each particular waterbody, its number of reaches and its required degree of discretization. Such a compilation will avoid the cost of praviding for more computer storage than is necessary.

To implement this program the user must specify the maximum size for the basic variables described in Table 8.2. These 18 variables determine the size of the dimension statements. The corresponding input formats are given in Figure 8.2. Figures 8.3 and 8.4 illustrate the flow of this particular procedure which is implemented by a combination of a short FORTRAN program which fills the dimensioned arrays and produces a control dataset for replacing cards in the Source Program using the IBM utility IEBUPDTE. The result of these operations is a newly dimensioned source program, ready for compilation.

8.4 Job Control Language (IBM)

Job control language listings for IBM operating systems are included at this point to facilitate applications with IBM equipment and to provide guidelines for users who wish to implement the program using the equipment of other manufacturers.

Tables 8.3, 8.4, 8.5, and 8.6 list the job control language for compilation, link editing, execution, and plotting respectively. These are to be used as guides: the actual JCL will depend on the user's computer facility.

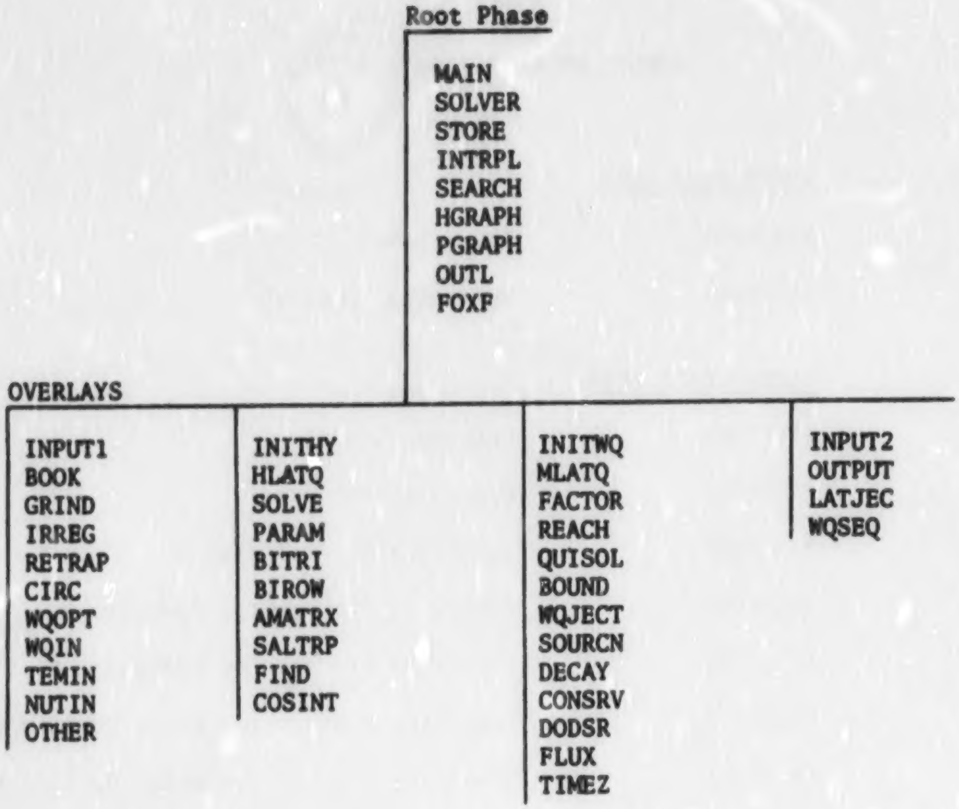

Root Phase
MAIN
SOLVER
STORE
INTRPL
SEARCH
HGRAPH
PGRAPH
OUTL
FOXF
OVERLAYS
INPUT1
BOOK
GRIND
IRREG
RETRAP
CIRC
WQOPT
WQIN
TEMIN
NUTIN
OTHER
INITHY
HLATQ
SOLVE
PARAM
BITRI
BIROW
AMATRX
SALTRP
FIND
COSINT
INITWQ
MLATQ
FACTOR
REACH
QUISOL
BOUND
WQJECT
SOURCN
DECAY
CONSRV
DODSR
FLUX
TIMEZ
INPUT2
OUTPUT
LATJEC
WQSEQ

FIGURE 8.1 OVERLAY STRUCTURE

TABLE 8.1

INPUT AND OUTPUT DATA SETS

INPUT DATA SETS

FT05F001	Input Data
FT10F001	Hydraulic Solution

OUTPUT DATA SETS

FT06F001	Printed Output
FT10F001	Hydraulic Solution
FT11F001	Water Quality Solution
FT12F001	Temporary Storage for Hydrograph
FT13F001	Temporary Storage for Hydraulic Profiles
FT14F001	Temporary Storage for Water Quality Graphs
FT15F001	Temporary Storage for Water Quality Profile

TABLE 8.2

LIST OF BASIC VARIABLES DETERMINING ARRAY SIZES

1. kjh - maximum number of hydraulic mesh points in a network
2. kji - maximum total of table entries for computational channel cross-section data
3. kjq - maximum number of water quality mesh points in a network
4. nk - maximum number of reaches in a network
5. nl - maximum number of lateral inflows in a network
6. nil - maximum number of table entries for lateral inflows
7. nzq - maximum number of table entries for hydraulic boundary conditions
8. ncf - maximum number of table entries for water quality boundary conditions
9. nj - maximum number of injection points
10. nij - maximum number of table entries for injection points
11. ln - maximum number of constituents
12. njh - maximum number of hydraulic mesh points per reach
13. njq - maximum number of water quality mesh points per reach
14. nn - maximum number of nodes ($\geq$nk + 1)
15. ngra - maximum number of time graphs hydro or quality
16. npro - maximum number of profiles
17. ntem - maximum number of table entries for meteorological conditions
18. matr - maximum number of elements in banded node matrix, maximum value (full matrix) = $(2\text{x no. reaches} + \text{no. nodes})^2$ For large systems reduction may be worthwhile. Output will give actual size required.

CARD 1

SWITCH TO CONTROL LISTING OF UTILITY OPERATIONS

LISTKY							
I5							
10	20	30	40	50	60	70	80

LISTKY = 0   No list option on IBM IEBUPDTE utility
LISTKY > 0   LIST = All option generated on IBM IEBUPDTE UTILITY

CARD 2,3

SIZES OF BASIC VARIABLES

ISIZE (1)	ISIZE (2)	ISIZE (3)	ISIZE (4)	ISIZE (5)	ISIZE (6)	ISIZE (7)	ISIZE (8)	ISIZE (9)	ISIZE (10)	ISIZE (11)	ISIZE (12)	ISIZE (13)	ISIZE (14)	ISIZE (15)	ISIZE (16)
I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	I5
	10		20		30		40		50		60		70		80

Numerical size of 18 basic variables as described in Table 8.3.
Use 2 cards, ISIZE(17) and ISIZE(18) being in columns 1-5, 6-10 of the second card.

FIGURE 8.2 INPUT FORMATS FOR PROGRAM TO MODIFY DIMENSIONS

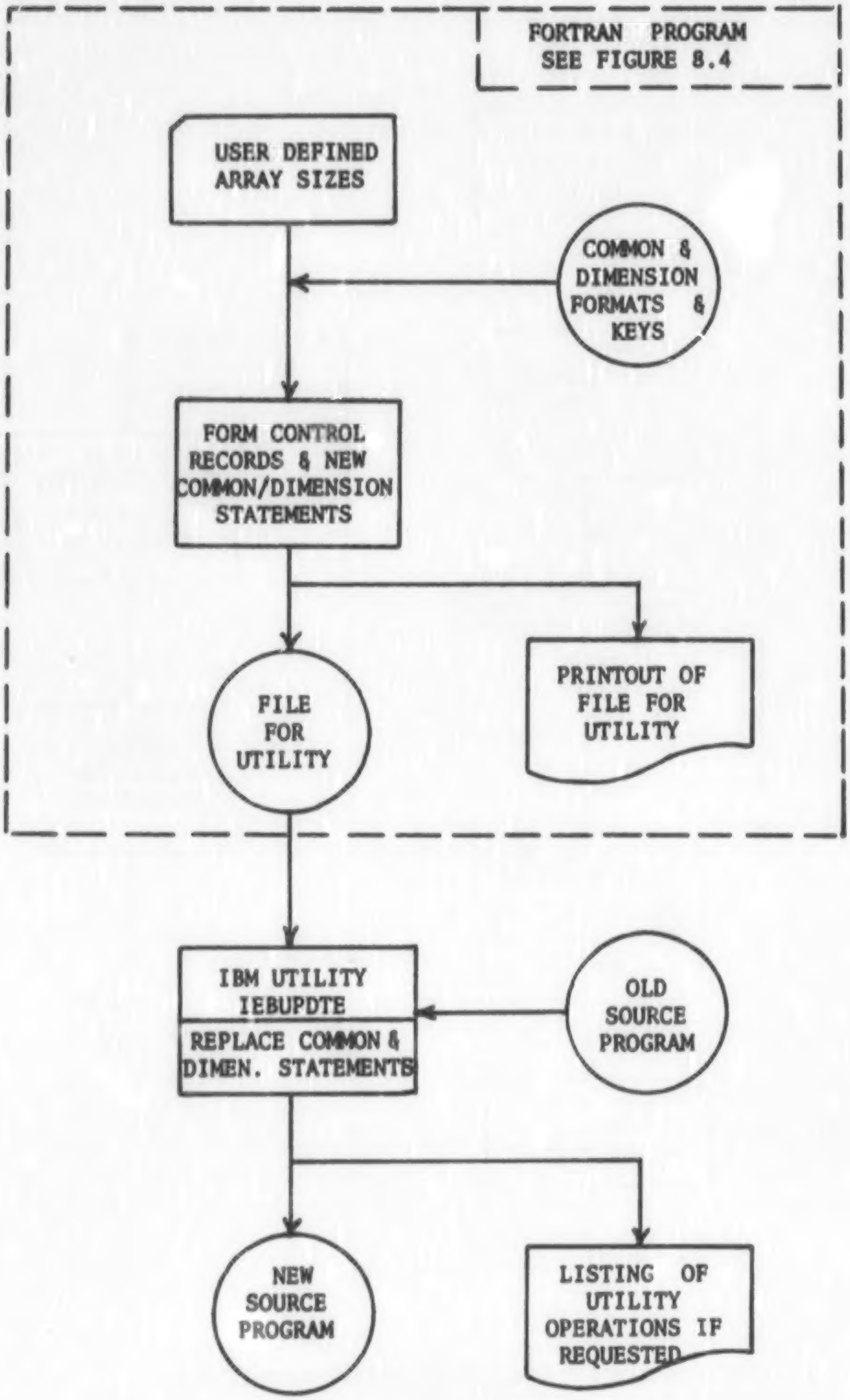

FORTRAN PROGRAM
SEE FIGURE 8.4
USER DEFINED ARRAY SIZES
COMMON & DIMENSION FORMATS & KEYS
FORM CONTROL RECORDS & NEW COMMON/DIMENSION STATEMENTS
FILE FOR UTILITY
PRINTOUT OF FILE FOR UTILITY
IBM UTILITY IEBUPDTE
REPLACE COMMON & DIMEN. STATEMENTS
OLD SOURCE PROGRAM
NEW SOURCE PROGRAM
LISTING OF UTILITY OPERATIONS IF REQUESTED

FIGURE 8.3 GENERAL FLOW DIAGRAM OF SYSTEM TO MODIFY DIMENSIONS

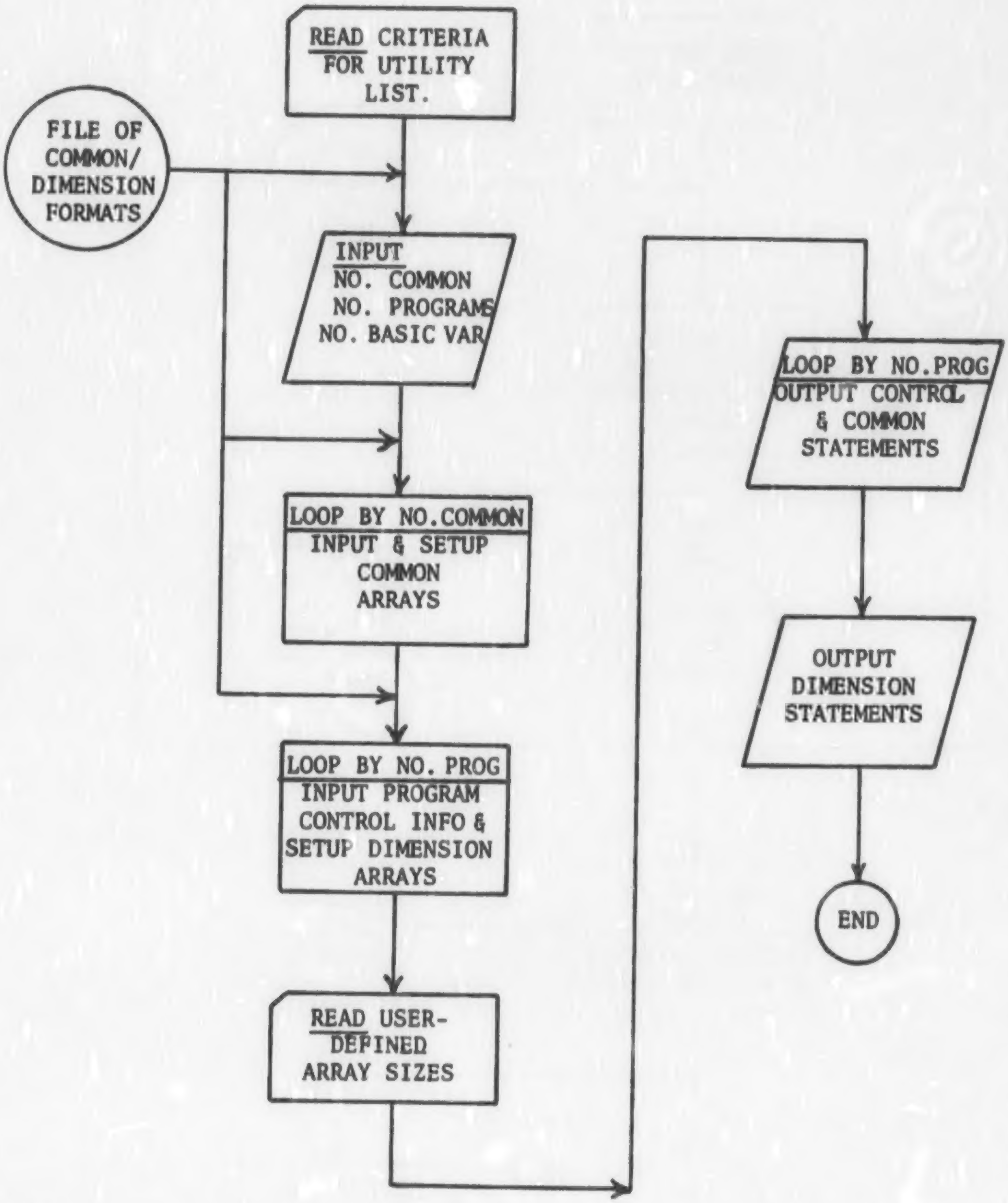

READ CRITERIA FOR UTILITY LIST.
FILE OF COMMON/ DIMENSION FORMATS
INPUT
NO. COMMON
NO. PROGRAMS
NO. BASIC VAR
LOOP BY NO.COMMON
INPUT & SETUP COMMON ARRAYS
LOOP BY NO. PROG
INPUT PROGRAM CONTROL INFO & SETUP DIMENSION ARRAYS
READ USER-DEFINED ARRAY SIZES
LOOP BY NO.PROG
OUTPUT CONTROL & COMMON STATEMENTS
OUTPUT DIMENSION STATEMENTS
END

FIGURE 8.4 FLOW DIAGRAM OF PROGRAM TO MODIFY DIMENSIONS

TABLE 8.3 SAMPLE COMPILATION JCL

```
//JOBLIB DD  DSN=SYS1.FORTH225,DISP=SHR
//STEPH EXEC FORTHC,REGION=256K
//FORT.SYSLIN DD UNIT=TAPE,SPACE=,DISP=(,KEEP),LABEL=RETPD=8031,
//        DSN=OUTOBJ
//FORT.SYSIN DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSN=SOURBIG(MAIN)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(AMATRX)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(BIROW)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(BITRI)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(BOOK)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(BOUND)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(CIRC)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(COSINT)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(FACTOR)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(FIND)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(GRIND)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(HGRAPH)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(HLATO)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(INITHY)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(INITWO)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(INPUT1)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(INPUT2)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(INTRPL)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(IRREG)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(MLATO)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(OUTPUT)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(PARAM)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(PGRAPH)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(REACH)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(RETRAP)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(SALTRP)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(SEARCH)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(SOLVE)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(SOLVER)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(STORE)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(QUISOL)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(WOJECT)
```

TABLE 8.3 (Continued)

```
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(WOOPT)
// DD UNIT=2314,VOL=SER=HYDROS,CISP=SHR,DSNAME=SOURBIG(WOIN)
// CD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(TEMIN)
// DD UNIT=2314,VCL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(NUTIN)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(OTHER)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(LATJEC)
// DD UNIT=2314,VOL=SER=HYDROS,CISP=SHR,DSNAME=SOURBIG(WOSEO)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(SOURCN)
// DD UNIT=2314,VOL=SER=HYDROS,CISP=SHR,DSNAME=SOURBIG(DECAY)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(CONSRV)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(DODSR)
// CD UNIT=2314,VOL=SER=HYDRCS,DISP=SHR,DSNAME=SOURBIG(OUTL)
// DD UNIT=2314,VCL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(FLUX)
// DD UNIT=2314,VOL=SER=HYDROS,DISP=SHR,DSNAME=SOURBIG(FOXF)
// DD UNIT=2314,VOL=SER=HYDROS,CISP=SHR,DSNAME=SOURBIG(TIMEZ)
/*
```

TABLE 8.3 SAMPLE LINK EDITING JCL

```
//STEPH EXEC LKED,PARM.LKED='LIST,MAP,OVLY'
//LKED.SYSLMOD DD DSN=NOBJ,UNIT=2314,VOL=SER=HYDROS,DISP=OLD
//LKED.SYSLIB DD DSN=SYS1.ERROPT.FORTLIB,DISP=SHR
//       DD DSN=SYS1.GRUMLIB,DISP=SHR
//TAPE1 DD UNIT=TAPE,VOL=SER=062062,LABEL=(,SL),DSN=OUTOBJ,
//      DISP=(OLD,KEEP)
//LKED.SYSIN DD *
 INCLUDE TAPE1
  ENTRY MAIN
 INSERT MAIN,SOLVER,STORE,INTRPL,SEARCH,HGRAPH,PGRAPH,OUTL,FOXF
 OVERLAY ALPHA
 INSERT INPUT1,BOOK,GRIND,IRREG,RETRAP,CIRC,NOOPT,NQIN,TEMIN,NUTIN,    *
               OTHER
 OVERLAY ALPHA
 INSERT INITHY,HLATO,SOLVE,PARAM,BITRI,BIROW,AMATRX,SALTRP,FIND,COSINT
 OVERLAY ALPHA
 INSERT INITWO,MLATO,FACTOR,REACH,QUISOL,BOUND,NQJECT,SOURCN,          *
               DECAY,CONSRV,DODSR,FLUX,TIMEZ
 OVERLAY ALPHA
 INSERT INPUT2,OUTPUT,LATJEC,NOSEO
 NAME HYD75E(R)
/*
```

TABLE 8.5 SAMPLE EXECUTION JCL

```
//S1    EXEC  PGM=HYD75E,REGION=226K,TIME=1,COND=(0,NE)
//STEPLIB DD DSN=WOBJ,UNIT=2314,VOL=SER=HYDROS,DISP=SHR
//FT05F001 DD DSN=SEND03,UNIT=SYSDA,DISP=(OLD,DELETE)
//FT06F001 DD SYSOUT=A
//FT10F001 DD DCB=(RECFM=VBS,LRECL=12,BLKSIZE=3520,BUFNO=1),UNIT=2314,
//    VOL=SER=HYDROS,DISP=(,KEEP),SPACE=(TRK,(22,4)),
//    DSN=HKNEW4
//FT11F001 DD DUMMY,DCB=(RECFM=VBS,LRECL=172,BLKSIZE=2400)
//FT12F001 DD UNIT=SYSDA,DSNAME=JUNK12,DISP=(NEW,DELETE),
//    SPACE=(TRK,(40)),DCB=(RECFM=VBS,LRECL=12,BLKSIZE=2059,BUFNO=1)
//FT13F001 DD UNIT=SYSDA,DSNAME=JUNK13,DISP=(NEW,DELETE),
//    SPACE=(TRK,(40)),DCB=(RECFM=VBS,LRECL=12,BLKSIZE=2059,BUFNO=1)
//FT14F001 DD UNIT=SYSDA,DSNAME=JUNK14,DISP=(NEW,DELETE),
//    SPACE=(TRK,(40)),DCB=(RECFM=VBS,LRECL=20,BLKSIZE=2059,BUFNO=1)
//FT15F001 DD UNIT=SYSDA,DSNAME=JUNK15,DISP=(NEW,DELETE),
//    SPACE=(TRK,(40)),DCB=(RECFM=VBS,LRECL=20,BLKSIZE=2059,BUFNO=1)
//FT16F001 DD  DUMMY,DCB=(RECFM=VBS,LRECL=172,BLKSIZE=2059)
//FT17F001 DD DUMMY,DCB=(RECFM=VBS,LRECL=172,BLKSIZE=2059)
//SYSUDUMP DD SYSOUT=A
/*
```

TABLE 8.6 SAMPLE PLOTTING JCL

```
//STEP1 EXEC PGM=PLOT10,TIME=(,10),REGION=92K
//STEPLIB DD DSN=FHOBJ,UNIT=2314,VOL=SER=HYDROS,DISP=SHR
//FT10F001 DD UNIT=2314,VOL=SER=HYDROS,DISP=(OLD,KEEP),
//        DSN=XXXXXX
//FT36F001 DD UNIT=TAPE,DSN=LEW.CALCOMP,DISP=(,KEEP),
//          DCB=(RECFM=VS,LRECL=504,BLKSIZE=508,DEN=2),
//          LABEL=RETPD=1
//FT06F001 DD SYSOUT=A
//FT05F001 DD * DATA TYPEIN
/*
```

8.4.1 Record Lengths, Block Sizes and Space Allocation

There are two principal variables in the determination of correct record lengths for the temporary and permanent files used with the program. These variables are: (1) the total number of computational (not user defined) hydraulic sections and (2) the total number of water quality sections. These numbers are best obtained by a preliminary run for input editing purposes only.

A. Record Lengths

The record length for the hydraulic files (FT10, FT12, FT13) is always 12 bytes, (2, 4-byte words plus a 4-byte count field). The record length for water quality output file (FT11) is: (number of water quality sections) x 4 + 4 bytes. The temporary files FT14 and FT15 for water quality graphs and profiles will both have a record length equal to: (total number of water quality parameters) x 4 + 4 bytes. Files FT16 and FT17 are not in use at this time.

B. Block Sizes

As the record form is variable-block-spanned (VBS), block size is not critical, but can be optimized. For files FT10 and FT11 defined on an IBM 2314 disk, optimum block sizes are 3520 or 7294 bytes. IBM 3330 disks have optimum block sizes of 2059, 2498, 3156, 4253, 6447 and 13,030 bytes.

C. Space

To estimate the amount of space required for the hydraulic output (FT10) one begins with: (total number of hydraulic section) x 12, which equals the number of bytes per timestep. The space required is then estimated by multiplying the total number of timesteps per run times this figure. For water quality (FT11) one beings with: (number of water quality sections) x 4 + 4 bytes. This quantity, the record length, is then multipifed by the number of water quality parameters being calculated. This gives the number of bytes per time step. Again one can multiply by the number of timesteps per run to get a total value. (Remember that the timestep for water quality calculation can be different from that for hydraulic calculations.)

8.5 Programmed Error Messages and Traps

In a programming system of this size the number of different errors and omissions possible through the incorrect or misunderstood preparation of input data is significant. It is recognized that this particular programming system, being a developmental system, represents the combined programming efforts of many investigators. There are undoubtedly some particular combinations of input-selected actions (flow paths) which may discover an error or program bug. During the application of Surveyer, Nenniger & Chenevert (1973, 1974) to the St. Lawrence River considerable additional programming was implemented to trap certain types of errors and also to edit errors in the input data. It is through these traps and error messages that the user will be able to correct his input data and proceed to the calculations with the minimum of program debugging. Included in these error diagnostics is the possibility of disabling the computation by timestep so that the computer can check out the input data.

Despite the effort made by all those who have developed and applied this program, it is recognized that errors may exist and may appear from time to time. It is hoped that users will communicate any findings to the R.M. Parsons Laboratory so that an updated version of the computer program can be maintained.

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12. Thatcher, M.L., Pearson, H.W., and Mayor-Mora, R.E., "Application of a Dynamic Network Model to Hydraulic and Water Quality Studies of the St. Lawrence River", 2nd Annual Symposium of the Waterways, Harbours and Coastal Engineering Division, ASCE, San Francisco, September 1975.

APPENDIX I. INPUT DATA AND OUTPUT LISTING FOR ESTUARY TEST CASE

I.a Input Data for Estuary Hydrodynamic Solution

```
TEST CASE HYDRODYNAMICS AND SALINITY UNSTEADY FLOW                              Card Group A
          1         2         1         2         2
          1         2         2
          1         3
S                   0
          1        48    44640.        3.0        6    0.05
          2         3         0
          1         1         1         2
          2         2         2         3
REACH ONE
          1         2         1         1                                          Card Group B
 .00001                  .018
          1         5     13.0       17.0      10000.     2500.
   10000.    1000.        0.2                  15.1      -1956.
REACH TWO
          2         2         1         1
 0.00001                  .018
          1         5     13.0       17.0      20000.     2500.
  20000.    1000.         0.0                  15.0      -7726.
WATER QUALITY DESCRIPTION
S                   1                                                             Card Group C
  50.       15000.      30000.
                    1         15
   0.        1000.      2000.      3000.      3500.      4000.      4500.
 5000.       5500.      6000.      6500.      7000.      8000.      9000.
 10000.
OVERRIDES
S                   1
                    3
   0.         0.
 5000.       0.
 10000.             0.
                    2         25
   0.        1000.      2000.      3000.      4000.      5000.      6000.
 7000.       8000.      8500.      9000.      9500.     10000.     10500.
  11000.     11500.     12000.     13000.     14000.     15000.     16000.
 17000.      18000.     19000.     20000.
```

```
OVERRIDES           2
S                  17
        0.      0.
    5000.        0.
    8000.        0.
    8500.       10.
  9000.        20.
     9500.     55.
   10000.     150.
   11000.      525.
  12000.      1175.
13000.         2050.
   14000.     3625.
   15000.    6550.
   16000.    10025.
   17000.    12700.
   18000.    13545.
   19000.     13630.
   20000.    15000.
DESCRIPTION OF LATERAL INFLOWS                                                  Card Group D
          0
DESCRIPTION OF INJECTIONS                                                       Card Group E
          0
HYDRAULIC DESCRIPTION OF THE NODES                                              Card Group F
          1          2          1          1
              15.10      1000.
          2          0
          3          1          3          1
             15.0       1000.      44640.     4.0        0.
HYDRAULIC OUTPUT PARAMETERS                                                     Card Group G
          2
          1  10000.             1
          2  20000.             1
          4
          1          24         1
          2          24         1
```

```
             1          48          1
             2          48          1
WATER QUALITY BOUNDARY CONDITIONS
             1          2           1                                  Card Group H
S                                                  1
                                          0.0
             2          0
             3          4           1              1
  0.0078
S             15000.
WATER QUALITY OUTPUT
            3                                                          Card Group I
            1  5000.               1
            1  10000.              1
            2   10000.             1
            4
            1           8          1
            2           8          1
            1          16          1
            2          16          1
```

I.b Partial Output Estuary Hydrodynamic Solution

```
TEST CASE HYDRODYNAMICS AND SALINITY UNSTEADY FLOW

**************************************************************************************************************

  HYDRAULIC SOLUTION OPTIONS

      SOLUTION COMPUTATIONS = EXECUTED
      SOLUTION TYPE = TRANSIENT
      SOLUTION STORAGE = EXECUTED
      NETWORK TYPE = ESTUARY
      HYDRAULIC INITIALIZATION FROM TAPE = DELETED

  WATER QUALITY SOLUTION OPTIONS

      SOLUTION COMPUTATIONS = EXECUTED
      SOLUTION TYPE = TRANSIENT
      SOLUTION STORAGE = DELETED


   WATER  QUALITY  PARAMETERS       N-TAYLOR MULTIPLE =    3

   SALINITY            CALCULATED

 NO OUTPUT TO OFFLINE FILES

   SOLUTION TIME PARAMETERS
                                                                  LENGTH OF PERIOD =  44640.0
        NUMBER OF PERIODS =    1                                  LENGTH OF HYDRAULIC TIME STEP =     930.0
        NUMBER OF HYDRAULIC TIME STEPS PER PERIOD =  48
             MAXIMUM ITERATIONS FOR INITIAL CONDITION =     6
             ERROR TOLERANCE FOR INITIAL CONDITION = 0.0500
             NUMBER OF LEAD-IN PERIODS TO BE READ FROM TAPE =    0
             NUMBER OF LEAD IN INCREMENTS IF RIVER STUDY =    0
        NUMBER OF WATER QUALITY TIME STEPS PER PERIOD =  16      LENGTH OF WATER QUALITY TIME STEP =   2790.0

   NETWORK CONTAINS  2 BRACHES WHICH CONNECT  3 JUNCTION AND BOUNDARY NODES           0 CONTROL STRUCTURE(S)
```

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*****************************************************************************************************

  HYDRAULIC DESCRIPTION OF THE REACHES

*****************************************************************************************************


DESCRIPTION FOR REACH      1        REACH ONE

     CROSS-SECTION SHAPE = RECTANGULAR PRISMATIC
     BOTTOM SLOPE = CONSTANT
     FRICTION COEFFICIENT = MANNING

     NO ICE COVER

     BOTTOM SLOPE = 0.000010     SIDE SLOPE =  0.0                  TOTAL LENGTH OF REACH =     10000.00 FT
     ESTIMATED MESH SPACING =  2500.00 FT
     COMPUTED MESH SPACING =  2500.00 FT
     NUMBER OF HYDRAULIC MESH POINTS =    5
     DATA CROSS-SECTIONS = 1     TABLE ENTRIES =  5     FIRST DEPTH =   11.000 FT     LAST DEPTH =   17.000 FT

     SECTION  1     X =   10000.00 FT     MANNINGS N = 0.0180
                     BOTTOM WIDTH =  1000.00 FT     BOTTOM ELEV =   0.200 FT     RADIUS =  0.0   FT
                     INITIAL SURFACE ELEVATION =  15.100 FT     INITIAL DISCHARGE =   -1956.00 CFS
DESCRIPTION FOR REACH      2        REACH TWO

     CROSS-SECTION SHAPE = RECTANGULAR PRISMATIC
     BOTTOM SLOPE = CONSTANT
     FRICTION COEFFICIENT = MANNING

     NO ICE COVER

     BOTTOM SLOPE = 0.000010     SIDE SLOPE =  0.0                  TOTAL LENGTH OF REACH =     20000.00 FT
     ESTIMATED MESH SPACING =  2500.00 FT
     COMPUTED MESH SPACING =  2500.00 FT
     NUMBER OF HYDRAULIC MESH POINTS =    9
     DATA CROSS-SECTIONS = 1     TABLE ENTRIES =  5     FIRST DEPTH =   11.000 FT     LAST DEPTH =   17.000 FT

     SECTION  1     X =   20000.00 FT     MANNINGS N = 0.0180
                     BOTTOM WIDTH =  1000.00 FT     BOTTOM ELEV =   0.0   FT     RADIUS =  0.0   FT
                     INITIAL SURFACE ELEVATION =  15.000 FT     INITIAL DISCHARGE =   -7726.00 CFS

*************************************************************
*                                                           *
*   14 STORAGE LOCATIONS REQUIRED FOR HYDRAULIC MESH ARRAYS *
*                                                           *
*************************************************************

*********************************************
*                                           *
*   70 STORAGE LOCATIONS REQUIRED FOR GRAPHS *
*                                           *
*********************************************
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****************************************************************************************************

HYDRAULIC DESCRIPTION OF THE NODES

****************************************************************************************************


 PRESCRIBED HYDRAULIC BOUNDARY CONDITIONS FOR NODE  1     TYPE = DISCHARGE
      NUMBER OF TABLE ENTRIES =   1     TIME DEPENDENCE = CONSTANT

          TIME (SEC)      SURFACE ELEVATION (FT)      DISCHARGE (CFS)
             0.0                 15.100                   1000.00

 PRESCRIBED HYDRAULIC BOUNDARY CONDITIONS FOR NODE  2     TYPE = JUNCTION

 PRESCRIBED HYDRAULIC BOUNDARY CONDITIONS FOR NODE  3     TYPE = SURFACE ELEV
      NUMBER OF TABLE ENTRIES =   1     TIME DEPENDENCE = SINUSOIDAL

          PERIOD (SEC)      RANGE (CFS OR FT)      TIME LAG (SEC)      MEAN SURF ELEV (FT)      MEAN DISCHARGE (CFS)
           44640.00               4.00                  0.0                  15.00                    1000.00

 *****************************************************************
 *                                                               *
 *    2 STORAGE LOCATIONS REQUIRED FOR HYDRAULIC BOUNDARY CONDITIONS *
 *                                                               *
 *****************************************************************

****************************************************************************************************
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****************************************************************************************************

        OUTPUT FOR CYCLE    1

****************************************************************************************************

HYDROGRAPH FOR REACH     1     REACH ONE
        SECTION          5  X =    10000.0  DURING PERIOD  1

        TIME (SEC)     SURFACE ELEVATION (FT)       DEPTH (FT)      DISCHARGE (CFS)      VELOCITY (FT/SEC)
              0.                 15.10                  14.90             -1956.                 -0.13
            930.                 15.45                  15.25             -2313.                 -0.15
           1860.                 15.68                  15.48             -1037.                 -0.07
           2790.                 15.83                  15.63              -966.                 -0.06
           3720.                 16.07                  15.87             -1475.                 -0.09
           4650.                 16.32                  16.12             -1733.                 -0.11
           5580.                 16.55                  16.35             -1508.                 -0.09
           6510.                 16.73                  16.53              -932.                 -0.06
           7440.                 16.86                  16.66              -413.                 -0.02
           8370.                 16.97                  16.77              -110.                 -0.01
           9300.                 17.05                  16.85                88.                  0.01
          10230.                 17.10                  16.90               437.                  0.03
          11160.                 17.12                  16.92               881.                  0.05
          12090.                 17.09                  16.89              1253.                  0.07
          13020.                 17.08                  16.88              1592.                  0.09
          13950.                 16.95                  16.75              1895.                  0.11
          14880.                 16.86                  16.66              2064.                  0.12
          15810.                 16.73                  16.53              2332.                  0.14
          16740.                 16.57                  16.37              2725.                  0.17
          17670.                 16.36                  16.16              3263.                  0.20
          18600.                 16.12                  15.92              3572.                  0.22
          19530.                 15.87                  15.67              3672.                  0.23
          20460.                 15.62                  15.42              3722.                  0.24
          21390.                 15.36                  15.16              3763.                  0.25
          22320.                 15.10                  14.90              3808.                  0.26
          23250.                 14.84                  14.64              3835.                  0.26
          24180.                 14.58                  14.38              3796.                  0.26
          25110.                 14.33                  14.13              3711.                  0.26
          26040.                 14.08                  13.88              3659.                  0.26
          26970.                 13.85                  13.65              3507.                  0.26
          27900.                 13.68                  13.48              3259.                  0.24
          28830.                 13.45                  13.25              3026.                  0.21
          29760.                 13.29                  13.09              2727.                  0.21
          30690.                 13.16                  12.96              2367.                  0.18
          31620.                 13.07                  12.87              2006.                  0.16
          32550.                 13.01                  12.81              1629.                  0.13
          33480.                 12.99                  12.79              1217.                  0.10
          34410.                 13.00                  12.80               868.                  0.07
          35340.                 13.05                  12.85               474.                  0.04
          36270.                 13.18                  12.98                78.                  0.01
          37200.                 13.27                  13.07              -320.                 -0.01
          38130.                 13.43                  13.23              -711.                 -0.06
          39060.                 13.60                  13.40              -879.                 -0.07
          39990.                 13.80                  13.60             -1099.                 -0.08
          40920.                 14.01                  13.81             -1421.                 -0.10
          41850.                 14.28                  14.08             -1714.                 -0.12
          42780.                 14.55                  14.35             -1962.                 -0.14
          43710.                 14.83                  14.63             -2207.                 -0.14
          44640.                 15.10                  14.90             -1957.                 -0.13
          AVERAGE DISCHARGE =     1010. CFS

HYDROGRAPH FOR REACH      2     REACH TWO
          SECTION     9  X =    20000.0  DURING PERIOD  1

          TIME (SEC)     SURFACE ELEVATION (FT)     DEPTH (FT)     DISCHARGE (CFS)     VELOCITY (FT/SEC)
                0.              15.00                 15.00            -7726.              -0.52
              930.              15.26                 15.26            -7022.              -0.51
             1860.              15.52                 15.52            -6367.              -0.41
             2790.              15.77                 15.77            -5753.              -0.36
             3720.              16.00                 16.00            -6482.              -0.40
             4650.              16.22                 16.22            -6756.              -0.42
             5580.              16.41                 16.41            -6202.              -0.38
             6510.              16.59                 16.59            -4479.              -0.27
             7440.              16.73                 16.73            -3363.              -0.20
             8370.              16.85                 16.85            -2499.              -0.15
             9300.              16.93                 16.93            -1909.              -0.11
            10230.              16.98                 16.98             -725.              -0.04
            11160.              17.00                 17.00              499.               0.03
            12090.              16.98                 16.98             1814.               0.11
            13020.              16.93                 16.93             2760.               0.16
            13950.              16.85                 16.85             3689.               0.22
            14880.              16.73                 16.73             4266.               0.25
            15810.              16.59                 16.59             5227.               0.32
            16740.              16.41                 16.41             6118.               0.38
            17670.              16.22                 16.22             7722.               0.48
            18600.              16.00                 16.00             8482.               0.53
            19530.              15.77                 15.77             8957.               0.56
            20460.              15.52                 15.52             9034.               0.59
            21390.              15.26                 15.26             9275.               0.61
            22320.              15.00                 15.00             9430.               0.63
            23250.              14.74                 14.74             9494.               0.64
            24180.              14.48                 14.48             9363.               0.65
            25110.              14.23                 14.23             9098.               0.64
            26040.              14.00                 14.00             8474.               0.63
            26970.              13.78                 13.78             8367.               0.61
            27900.              13.59                 13.59             7646.               0.56
            28830.              13.41                 13.41             6970.               0.52
            29760.              13.27                 13.27             6018.               0.46
            30690.              13.15                 13.15             4986.               0.38
            31620.              13.07                 13.07             3933.               0.30
            32550.              13.02                 13.02             2819.               0.22
            33480.              13.00                 13.00             1664.               0.11
            34410.              13.02                 13.02              604.               0.05
            35340.              13.07                 13.07             -591.              -0.05
            36270.              13.15                 13.15            -1755.              -0.13
            37200.              13.27                 13.27            -3960.              -0.30
            38130.              13.41                 13.41            -4274.              -0.32
            39060.              13.59                 13.59            -4632.              -0.34
            39990.              13.78                 13.78            -4648.              -0.34
            40920.              14.00                 14.00            -5971.              -0.43
            41850.              14.23                 14.23            -6933.              -0.49
            42780.              14.48                 14.48            -7518.              -0.52
            43710.              14.74                 14.74            -7767.              -0.53
            44640.              15.00                 15.00            -7727.              -0.52

          AVERAGE DISCHARGE =     1023. CFS

********************************************************************************************************


HYDRAULIC PROFILE, REACH      1     REACH ONE
          AT TIME    22320.0  OF PERIOD  1
```

```
              X (FT)      SURFACE ELEVATION (FT)      DEPTH (FT)      DISCHARGE (CFS)      VELOCITY (FT/SEC)
                 0.                15.11                 14.81              1000.                 0.07
              2500.                15.11                 14.83              1793.                 0.11
              5000.                15.10                 14.85              2404.                 0.16
              7500.                15.10                 14.88              3107.                 0.21
             10000.                15.10                 14.90              3808.                 0.26
HYDRAULIC PROFILE, REACH       2     REACH TWO
         AT TIME    22320.0  OF PERIOD  1

              X (FT)      SURFACE ELEVATION (FT)      DEPTH (FT)      DISCHARGE (CFS)      VELOCITY (FT/SEC)
                 0.                15.10                 14.90              3808.                 0.26
              2500.                15.11                 14.93              4655.                 0.31
              5000.                15.10                 14.95              5213.                 0.35
              7500.                15.10                 14.98              6059.                 0.40
             10000.                15.09                 14.99              6620.                 0.44
             12500.                15.07                 15.00              7467.                 0.50
             15000.                15.05                 15.00              8026.                 0.54
             17500.                15.01                 14.99              8873.                 0.59
             20000.                15.00                 15.00              9430.                 0.63
HYDRAULIC PROFILE, REACH       1     REACH ONE
         AT TIME    44640.0  OF PERIOD  1

              X (FT)      SURFACE ELEVATION (FT)      DEPTH (FT)      DISCHARGE (CFS)      VELOCITY (FT/SEC)
                 0.                15.10                 14.80              1000.                 0.07
              2500.                15.10                 14.83               259.                 0.02
              5000.                15.10                 14.85              -490.                -0.03
              7500.                15.10                 14.88             -1221.                -0.08
             10000.                15.10                 14.90             -1957.                -0.13
HYDRAULIC PROFILE, REACH       2     REACH TWO
         AT TIME    44640.0  OF PERIOD  1

              X (FT)      SURFACE ELEVATION (FT)      DEPTH (FT)      DISCHARGE (CFS)      VELOCITY (FT/SEC)
                 0.                15.10                 14.90             -1957.                -0.13
              2500.                15.07                 14.90             -3380.                -0.23
              5000.                15.10                 14.95             -3421.                -0.23
              7500.                15.07                 14.98             -4681.                -0.32
             10000.                15.10                 15.00             -4673.                -0.32
             12500.                15.07                 14.99             -6207.                -0.42
             15000.                15.09                 15.04             -6310.                -0.42
             17500.                15.03                 15.01             -7716.                -0.51
             20000.                15.00                 15.00             -7727.                -0.52

*****************************************************************************************************************
```

I.c Input Data for Estuary Water Quality Solution

```
TEST CASE HYDRODYNAMICS AND WATER QUALITY UNSTEADY FLOW                        Card Group A
              2             1              2             2             1
              1             1              1
              5             3
S                           0              1
T                           2              0
CBOD                        0              1
NUTR                        0              1
DO                          0              1             3
             10            48    44640.         3.0            1     0.05
              2             3              0
              1             1              1             2
              2             2              2             3
REACH ONE
              1             2              1             1
  .00001                        .018                                           Card Group B
              1             5    13.0      17.0          10000.      2500.
   10000.    1000.               0.2
REACH TWO                                                15.1        -1956.
              2             2              1             1
  0.00001                        .018
              1             5    13.0      17.0          20000.      2500.
   20000.    1000.               0.0
WATER QUALITY DESCRIPTION                                15.0        -7726.
S                           1
  50.        15000.              30000.                                        Card Group C
T                           0
CBOD                        1
CBOD                      0.1    1.047
NUTR                        1              0             5.
              4
    1           0.03
    5           0.18
   12           0.60
   24           0.01
DO                          0
```

```
                     2          25
    0.           1000.      2000.      3000.      4000.      5000.      6000.
   7000.        8000.      8500.      9000.      9500.      10000.     10500.
    11000.      11500.      12000.      13000.      14000.     15000.     16000.
   17000.       18000.    19000.      20000.
  OVERRIDES                2
  S                       17
          0.      0.
     5000.         0.
      8000.        0.
      8500.       10.
    9000.       20.
        9500.   55.
     10000.    150.
      11000.    525.
   12000.       1175.
  13000.         2050.
    14000.     3625.
    15000.    6550.
    16000.    10025.
    17000.    12700.
    18000.    13545.
    19000.      13630.
    20000.    15000.
  T                       1
       5000.         68.
  CBOD                    1
     5000.           3.0
  NH3                     3
   0.0          .2
   10000.       .3
   15000.      .3
  NC2                     2
          0.0       0.04
   15000.      .1
  NC3                     3
```

```
                      1        15
    0.       1000.      2000.        3000.     3500.      4000.     4500.
  5000.      5500.      6000.       6500.     7000.     8000.      9000.
  10000.
OVERRIDES             1
S                     3
   0.       0.
  5000.    0.
  10000.        0.
T                     1
    5000.           68.
CBOD                  1
   5000.           3.0
NH3                   4
  4500.       .2
   5000.       .5
   5500.        .2
  10000.       .2
NO2                   1
       0.0        0.04
NO3                   1
5000.                .5
PHYN                  1
5000.                .2
ZOON                  1
5000.                .2
PON                   3
  4500.        .1
 5000.               .3
  5500.          .1
DON                   3
  4500.        .1
 5000.               .3
  5500.          .1
DC                    1
        0.0        5.0
  0.          .4
 12000.      .5
 17000.      .1
PHYN              1
5000.            .2
ZOON              1
5000.            .2
PON               3
 0.0         .1
 10000.      .2
 15000.    .4
DON               1
5000.            .1
DO                1
       0.0       5.0
LATERAL INFLOWS                                                                      Card Group D

DESCRIPTION OF INJECTIONS                                                            Card Group E
         2
         1         1     5000.         1         1         5
CBOD      NH3       NO3        PON        DON
    0.      2502.     1668.     166.8      834.      834.
         2         2    10000.         1         1         5
3BOD      NH3       NO3        PON        DON
    0.      5004.     3336.     333.6      1668.     1668.
WATERQUALITY BOUNDARY CONDITIONS                                                     Card Group H
         1         1         1         1
S                          0.
T                         68.
CBOD                       3.
NH3                        .1
NO2                       .04
NO3                     .06
PHYN                      .25
ZOON                      .17
PON                        .1
```

```
DCN                       .05
DC                         8.
        2         0
        3         4         1         1
   .0078
S             15000.
T                68.
CBOD             3.7
NH3              .06
NO2             .01
NO3              .03
PHYN             .15
ZCON            .1
PCN             .1
DON             .1
DO              7.0
WATER QUALITY OUTPUT
       10
        1      2500.        10
        1      5000.        10
        1      7500.        10
        1     10000.        10
        2      5000.        10
        2      7500.        10
        2     10000.        10
        2     12500.        10
        2     15000.        10
        2     20000.        10
       10
        1        16          9
        2        16          9
        1         4         10
        2         4         10
        1         8         10
        2         8         10
        1        12         10
```

Card Group I

2	12	10
1	16	10
2	16	10

I.d Partial Output from Estuary Water Quality Solution

```
**********************************************************************************************************

TEST CASE HYDRODYNAMICS AND WATER QUALITY ESTUARY FLOW

**********************************************************************************************************

  HYDRAULIC SOLUTION OPTIONS

     SOLUTION COMPUTATIONS = DELETED
     SOLUTION TYPE = STEADY-STATE
     SOLUTION STORAGE = DELETED
     NETWORK TYPE = ESTUARY
     HYDRAULIC INITIALIZATION FROM TAPE = EXECUTED

  WATER QUALITY SOLUTION OPTIONS

     SOLUTION COMPUTATIONS = EXECUTED
     SOLUTION TYPE = STEADY-STATE
     SOLUTION STORAGE = EXECUTED


  WATER  QUALITY  PARAMETERS      [illegible] MULTIPLE =    1

 SALINITY             CALCULATED
 TEMPERATURE          CONSTANT
 B.O.D. (CARB.)       CALCULATED
 AMMONIA NITROGEN     CALCULATED
 NITRITE NITROGEN     CALCULATED
 NITRATE NITROGEN     CALCULATED
 PHYTOPLANKTON - N    CALCULATED
 ZOOPLANKTON - N      CALCULATED
 PARTICULATE ORG. - N CALCULATED
 DISSOLVED ORG.  - N  CALCULATED
 DISSOLVED OXYGEN     CALCULATED AS A FUNCTION OF C-BOD & N-BOD

OUTPUT TO OFFLINE FILES FOR

  SALINITY
  B.O.D. (CARB.)
  AMMONIA NITROGEN
  NITRITE NITROGEN
  NITRATE NITROGEN
  PHYTOPLANKTON - N
  ZOOPLANKTON - N
  PARTICULATE ORG. - N
  DISSOLVED ORG.  - N
  DISSOLVED OXYGEN

  SOLUTION TIME PARAMETERS                                                LENGTH OF PERIOD = [illegible]
                                                                          LENGTH OF HYDRAULIC TIME STEP =    [illegible]
       NUMBER OF PERIODS =  [illegible]
       NUMBER OF HYDRAULIC TIME STEPS PER PERIOD =  [illegible]
       NUMBER OF HYDRAULIC TIME STEPS FOR INITIAL CONDITION =     1
           MAXIMUM ITERATIONS FOR INITIAL CONDITION = 0.0[illegible]00
           ERROR TOLERANCE FOR INITIAL CONDITION
     [illegible]
     NUMBER OF LEAD-IN PERIODS TO BE READ FROM TAPE =   0
     NUMBER OF LEAD IN INCREMENTS IF STEADY STUDY =   1
  NUMBER OF WATER QUALITY TIME STEPS PER PERIOD =  16      LENGTH OF WATER QUALITY TIME STEP =   2700.0

NETWORK CONTAINS  2 REACHES WHICH CONNECT  3 JUNCTION AND BOUNDARY NODES                 1 CONTROL STRUCTURE(S)

   1   REACH ID =    1          UPSTREAM NODE =  1     DOWNSTREAM NODE =  2
```

```
****************************************************************************************************

WATERQUALITY BOUNDARY CONDITIONS

****************************************************************************************************

 PRESCRIBED WATER QUALITY BOUNDARY CONDITIONS FOR NODE  1     TYPE = CONCENTRATION

     NUMBER OF TABLE ENTRIES =   1     TIME DEPENDENCE = CONSTANT

          TABLE ENTRIES FOR SALINITY

              TIME      CONCENTRATION
               SEC           PPM
                0.     0.0

          TABLE ENTRIES FOR TEMPERATURE

              TIME      CONCENTRATION
               SEC          DEG.F
                0.    0.680000E+02

          TABLE ENTRIES FOR B.O.D. (CARB.)

              TIME      CONCENTRATION
               SEC           PPM
                0.    0.300000E+01

          TABLE ENTRIES FOR AMMONIA NITROGEN

              TIME      CONCENTRATION
               SEC           PPM
                0.    0.100000E+00

          TABLE ENTRIES FOR NITRITE NITROGEN

              TIME      CONCENTRATION
               SEC           PPM
                0.    0.400000E-01

          TABLE ENTRIES FOR NITRATE NITROGEN

              TIME      CONCENTRATION
               SEC           PPM
                0.    0.600000E-01

          TABLE ENTRIES FOR PHYTOPLANKTON - [illegible]

              TIME      CONCENTRATION
               SEC           PPM
                0.    0.250000E+00
```

```
      TABLE ENTRIES FOR ZOOPLANKTON - N

          TIME       CONCENTRATION
           SEC            PPM
            0.     0.170000E+00

      TABLE ENTRIES FOR PARTICULATE ORG. - N

          TIME       CONCENTRATION
           SEC          * PPM
            0.     0.100000E+00

      TABLE ENTRIES FOR DISSOLVED ORG.  - N

          TIME       CONCENTRATION
           SEC            PPM
            0.     0.500000E-01

      TABLE ENTRIES FOR DISSOLVED OXYGEN

          TIME       CONCENTRATION
           SEC            PPM
            0.     0.800000E+01
PRESCRIBED WATER QUALITY BOUNDARY CONDITIONS FOR NODE  2     TYPE = JUNCTION

PRESCRIBED WATER QUALITY BOUNDARY CONDITIONS FOR NODE  3     TYPE = OCEAN BOUNDARY
           TIME CONSTANT FOR CONCENTRATION CHANGE ON FLOOD =   0.780000E-02

           SPECIFIED OCEAN CONCENTRATION
           SALINITY                     15000.00    PPM
           TEMPERATURE                     68.00   DEG.F
           B.O.D. (CARB.)                   3.70    PPM
           AMMONIA NITROGEN                 0.06    PPM
           NITRITE NITROGEN                 0.01    PPM
           NITRATE NITROGEN                 0.03    PPM
           PHYTOPLANKTON - N                0.15    PPM
           ZOOPLANKTON - N                  0.10    PPM
           PARTICULATE ORG. - N             0.10    PPM
           DISSOLVED ORG.  - N              0.10    PPM
           DISSOLVED OXYGEN                 7.00    PPM

*****************************************************************
*                                                               *
*    2 STORAGE LOCATIONS REQUIRED FOR WATER QUALITY BOUNDARY CONDITIONS *
*                                                               *
*****************************************************************

*******************************************************************************************************
```

```
QUALITY GRAPH FOR REACH      1      REACH CSF
           SECTION     15  X =     5000.0  DURING PERIOD 10

     TIME   SALIN.   TEMP     CBOD     NH3      NO2      NO3      PHYT     ZOOP     PON      DOP       DO
   SECONDS   PPM    DEG.F     PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM
       0.      0.    68.00    3.95   1.2026   0.0685   0.1990   0.2320   0.1681   0.6851   0.5830    7.40
    2790.      0.    68.00    4.16   1.4188   0.0582   0.2095   0.2283   0.1657   0.7732   0.6599    7.33
    5580.      0.    68.00    4.39   1.6630   0.0609   0.2275   0.2238   0.1679   0.8682   0.7390    7.27
    8370.      0.    68.00    4.47   1.6732   0.0656   0.2355   0.2231   0.1695   0.8395   0.7683    7.21
   11160.      0.    68.00    4.15   1.4608   0.0658   0.2163   0.2231   0.1698   0.7923   0.6589    7.22
   13950.      0.    68.00    3.19   0.7076   0.0538   0.1471   0.2241   0.1697   0.4590   0.3450    7.31
   16740.      0.    68.00    2.88   0.2789   0.0405   0.1059   0.2247   0.1696   0.2081   0.1160    7.40
   19530.      0.    68.00    2.43   0.2139   0.0368   0.0891   0.2262   0.1715   0.1765   0.0928    7.43
   22320.      0.    69.00    2.50   0.2393   0.0367   0.0909   0.2259   0.1742   0.1888   0.1052    7.44
   25110.      0.    69.00    2.52   0.2229   0.0368   0.0887   0.2246   0.1776   0.1795   0.0988    7.47
   27900.      0.    69.00    2.58   0.2415   0.0367   0.0897   0.2225   0.1805   0.1875   0.1076    7.49
   30690.      0.    69.00    2.65   0.2779   0.0372   0.0925   0.2199   0.1817   0.2040   0.1250    7.52
   33480.      0.    68.00    2.75   0.3438   0.0373   0.0983   0.2176   0.1813   0.2358   0.1576    7.56
   36270.      0.    68.00    2.96   0.4997   0.0380   0.1138   0.2160   0.1799   0.3131   0.2331    7.56
   39060.      0.    68.00    3.41   0.8262   0.0621   0.1468   0.2152   0.1781   0.4764   0.3918    7.50
   41850.      0.    68.00    3.87   1.1578   0.0842   0.1807   0.2163   0.1770   0.6426   0.5890    7.45
   44640.      0.    68.00    3.95   1.2026   0.0687   0.1990   0.2170   0.1761   0.6858   0.5029    7.40

          AVERAGE CONCENTRATIONS

       0.      0.    68.00    3.28   0.7805   0.0457   0.1483   0.2218   0.1743   0.4551   0.3379    7.41
```

```
QUALITY GRAPH FOR REACH      1     REACH END
              SECTION     29  X =    10000.0  CURRENT PERIOD 1

   TIME   SALIN.   TEMP     CBOD    NH3      NO2      NO3      PHYT     ZOOP     POM      DOM       DO
 SECONDS   PPM    DEG.F     PPM     PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM
      0.    -0.    68.00    1.89  0.3499   0.0662   0.1212   0.2026   0.1694   0.2556   0.0997     7.10
   2790.     0.    68.00    1.92  0.3959   0.0719   0.1113   0.2027   0.1531   0.2812   0.1097     6.99
   5580.     0.    68.00    1.91  0.4097   0.0769   0.1150   0.1997   0.1562   0.2901   0.1111     6.93
   8370.    -0.    68.00    1.93  0.4261   0.0926   0.1423   0.2010   0.1628   0.3010   0.1132     6.62
  11160.    -0.    68.00    1.90  0.4176   0.0907   0.1432   0.1966   0.1641   0.2995   0.1051     6.91
  13950.     0.    68.00    1.88  0.3872   0.0768   0.1370   0.1916   0.1617   0.2917   0.1025     6.88
  16740.     0.    68.00    1.81  0.3325   0.0679   0.1287   0.1923   0.1626   0.2580   0.0879     6.95
  19530.     0.    68.00    1.87  0.2966   0.0598   0.1213   0.1986   0.1699   0.2370   0.0838     6.96
  22320.     1.    68.00    2.05  0.3560   0.0628   0.1268   0.2081   0.1773   0.2656   0.1081     6.90
  25110.     1.    68.00    2.25  0.4672   0.0765   0.1389   0.2057   0.1952   0.3185   0.1059     6.83
  27900.     0.    68.00    2.29  0.4768   0.0761   0.1381   0.2021   0.1862   0.3186   0.1061     6.87
  30690.    -0.    68.00    2.20  0.3677   0.0587   0.1239   0.1978   0.1957   0.2682   0.1119     6.98
  33480.    -0.    68.00    2.11  0.2788   0.0581   0.1126   0.1355   0.1950   0.2205   0.0869     7.05
  36270.    -0.    68.00    2.07  0.2531   0.0516   0.1101   0.1986   0.1836   0.2096   0.0760     7.05
  39060.    -0.    68.00    1.96  0.2531   0.0528   0.1088   0.1462   0.1780   0.2068   0.0726     7.10
  41850.    -0.    68.00    1.86  0.2072   0.0568   0.1101   0.1767   0.1629   0.2196   0.0803     7.17
  44640.    -0.    68.00    1.89  0.3580   0.0669   0.1215   0.1799   0.1630   0.2561   0.0991     7.09

          AVERAGE CONCENTRATIONS

      0.     0.    68.00    1.99  0.3588   0.0672   0.1270   0.1953   0.1709   0.2613   0.1025     6.96
```

```
QUALITY GRAPH FOR REACH      2     REACH TWO
             SECTION    25  X =    10000.0  DURING PERIOD 10

    TIME   SALIN.    TEMP     CBOD      NH3      NO2      NO3     PHYTN     ZOOP      PO4      DCB       DO
  SECONDS    PPM    DEG.F     PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM
       0.    106.   68.00     1.66   0.6626   0.0963   0.2258   0.1822   0.1677   0.6541   0.1908     6.62
    2790.    360.   69.00     1.93   0.7557   0.1095   0.2511   0.1892   0.1707   0.5191   0.2385     6.19
    5580.    990.   68.00     1.91   0.7865   0.1138   0.2558   0.1932   0.1728   0.5377   0.2418     6.32
    8370.   1635.   68.00     2.03   0.7984   0.1126   0.2515   0.1776   0.1718   0.5312   0.2087     6.29
   11160.   2289.   68.00     2.09   0.7836   0.1181   0.2822   0.1712   0.1677   0.5186   0.2891     6.33
   13950.   2288.   68.00     2.10   0.7878   0.1073   0.2827   0.1697   0.1678   0.5215   0.2519     6.33
   16740.   1658.   68.00     2.03   0.8065   0.1101   0.2891   0.1649   0.1697   0.5389   0.2578     6.35
   19530.    966.  *68.00     1.93   0.7970   0.1109   0.2500   0.1633   0.1718   0.5129   0.2521     6.39
   22327.    392.   69.00     1.80   0.7269   0.1361   0.2812   0.1718   0.1779   0.4981   0.2235     5.85
   25110.     79.   69.00     1.69   0.6121   0.0998   0.2261   0.1778   0.1793   0.4429   0.1740     6.45
   27900.    -18.   69.00     1.61   0.6988   0.0925   0.2090   0.1981   0.1832   0.3852   0.1357     6.48
   30690.     -7.   68.90     1.58   0.6939   0.0867   0.1998   0.1857   0.1919   0.3733   0.1371     6.54
   33480.      7.   69.00     1.86   0.6299   0.0833   0.2179   0.1822   0.1767   0.4811   0.2143     6.62
   36270.      7.   68.00     2.42   1.0190   0.0946   0.2868   0.1807   0.1786   0.6330   0.4059     6.62
   39060.     -1.   69.00     2.15   0.8900   0.0867   0.2330   0.1738   0.1680   0.5538   0.3309     6.69
   41850.      9.   68.00     1.52   0.5302   0.0982   0.1971   0.1628   0.1590   0.3967   0.1598     5.81
   44640.    106.   69.00     1.66   0.6527   0.0978   0.2280   0.1687   0.1673   0.4395   0.2000     6.61

             AVERAGE CONCENTRATIONS

       0.    660.   68.00     1.89   0.7228   0.0995   0.2331   0.1769   0.1733   0.4875   0.2330     6.48
```

```
QUALITY GRAPH FOR REACH      2     REACH TWO
              SECTION     37  X =    15000.0  DURING PERIOD 10

   TIME   SALIN.    TEMP     CBOD     NH3      NO2      NO3     PHYN     ZOON     DCS      DCN       DO
 SECONDS   PPM     DEG.F     PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM
      0.   6461.   58.00     2.37  0.4347  0.0475  0.1040  0.1520  0.1179  0.3712  0.1475     6.47
   2790.   9926.   68.00     2.70  0.3057  0.0499  0.1398  0.1513  0.1201  0.2360  0.1299     6.68
   5580.  10876.   68.00     2.90  0.2066  0.0602  0.0991  0.1695  0.1272  0.2228  0.1170     6.77
   8370.  11176.   68.00     3.04  0.2282  0.0176  0.0320  0.1478  0.1191  0.1925  0.1140     6.75
  11160.  11526.   69.00     3.28  0.2267  0.0376  0.0925  0.1473  0.1109  0.1912  0.1121     6.72
  13950.  10985.   69.00     2.95  0.2600  0.0481  0.0949  0.1496  0.1255  0.2127  0.1160     6.60
  16740.   9893.   68.00     2.74  0.3165  0.0562  0.1140  0.1498  0.1319  0.2566  0.1251     6.66
  19530.   7582.   68.00     2.48  0.4282  0.0713  0.1502  0.1506  0.1413  0.3121  0.1427     6.49
  22320.   5872.   68.00     2.26  0.5465  0.0875  0.1956  0.1535  0.1518  0.3922  0.1696     6.43
  25110.   3691.   69.00     2.10  0.6596  0.1020  0.2131  0.1597  0.1636  0.4505  0.1990     6.26
  27900.   2223.   68.00     1.96  0.7270  0.1109  0.2391  0.1618  0.1696  0.4925  0.2157     6.34
  30690.   1358.   68.00     1.55  0.7394  0.1162  0.2656  0.1633  0.1721  0.5029  0.2158     6.39
  33480.   1010.   68.00     1.70  0.7279  0.1152  0.2676  0.1681  0.1727  0.4940  0.2077     6.60
  36270.   1053.   68.00     1.77  0.7200  0.1168  0.2679  0.1635  0.1716  0.4950  0.2016     6.39
  39060.   1376.   68.00     1.72  0.6893  0.1132  0.2746  0.1563  0.1632  0.4778  0.1900     6.68
  41850.   2692.   58.00     1.78  0.6085  0.1023  0.2111  0.1471  0.1492  0.4226  0.1699     6.62
  44640.   6451.   68.00     2.36  0.4683  0.0968  0.1688  0.1527  0.1193  0.3625  0.1505     6.60

          AVERAGE CONCENTRATIONS

      0.   6058.   68.00     2.36  0.4941  0.0799  0.1705  0.1542  0.1466  0.3519  0.1611     6.58
QUALITY GRAPH FOR REACH      2     REACH TWO
              SECTION     43  X =    20000.0  DURING PERIOD 10

   TIME   SALIN.    TEMP     CBOD     NH3      NO2      NO3     PHYN     ZOON     DCS      DCN       DO
 SECONDS   PPM     DEG.F     PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM
      0.  15000.   69.00     3.70  0.0600  0.0100  0.0100  0.1500  0.1000  0.1000  0.1000     7.00
   2790.  15000.   69.00     3.70  0.0600  0.0100  0.0100  0.1500  0.1000  0.1000  0.1000     7.00
   5580.  15000.   69.00     3.70  0.0600  0.0100  0.0100  0.1500  0.1000  0.1000  0.1000     7.00
   8370.  15000.   68.00     3.70  0.0600  0.0100  0.0100  0.1500  0.1000  0.1000  0.1000     7.00
  11160.  15166.   68.00     3.72  0.0647  0.0106  0.0312  0.1505  0.1024  0.1122  0.0998     6.92
  13950.  15417.   68.00     3.72  0.0693  0.0112  0.0325  0.1520  0.1053  0.1062  0.0997     6.85
  16740.  15257.   68.00     3.63  0.0756  0.0123  0.0382  0.1494  0.1063  0.1031  0.0979     6.81
  19530.  14182.   68.00     3.36  0.1139  0.0191  0.0468  0.1430  0.1038  0.1288  0.0951     6.77
  22320.  12295.   68.00     3.06  0.1385  0.0379  0.0761  0.1438  0.1194  0.1771  0.1036     6.68
  25110.  10285.   68.00     2.77  0.2992  0.0513  0.1330  0.1449  0.1310  0.2363  0.1170     6.58
  27900.   7956.   69.00     2.44  0.4139  0.0791  0.1672  0.1672  0.1426  0.3046  0.1362     6.50
  30690.   6237.   68.00     2.27  0.5126  0.0885  0.1760  0.1689  0.1505  0.3575  0.1525     6.45
  33480.   5869.   68.00     2.37  0.5419  0.0916  0.1337  0.1696  0.1535  0.3815  0.1587     6.82
  36270.  15000.   68.00     3.70  0.0600  0.0100  0.0100  0.1500  0.1000  0.1000  0.1000     7.00
  39060.  15000.   69.00     3.70  0.0600  0.0100  0.0100  0.1500  0.1000  0.1000  0.1000     7.00
  41850.  15000.   68.00     3.70  0.0600  0.0100  0.0100  0.1500  0.1000  0.1000  0.1000     7.00
  44640.  15000.   69.00     3.70  0.0600  0.0100  0.0100  0.1500  0.1000  0.1000  0.1000     7.00

          AVERAGE CONCENTRATIONS

      0.  12909.   68.00     3.32  0.1697  0.0243  0.0657  0.1547  0.1119  0.1537  0.1049     6.81
```

```
CONCENTRATION PROFILE, REACH     1     REACH ONE
                 AT TIME   44640.0  OF PERIOD 10

   DISTANCE SALIN.    TEMP     CBOD      NH3      NO2      NO3     PHYT     ZOOP      PON      DON       DO
     FEET     PPT    DEG.F     PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM
       0.       0.   68.00     1.00   0.1000 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
     500.      -0.   68.00     2.90   0.0963   0.0395   0.0591   0.2490   0.1680   0.0979   0.0484     8.03
    1000.      -0.   68.00     2.89   0.0963   0.0383   0.0628   0.2476   0.1627   0.1012   0.0455     7.94
    1500.      -0.   68.00     2.72   0.0960   0.0393   0.0617   0.2444   0.1665   0.0998   0.0449     7.93
    2000.       0.   68.00     2.69   0.1026   0.0379   0.0666   0.2399   0.1673   0.1067   0.0436     7.78
    2500.      -0.   68.00     2.61   0.0989   0.0379   0.0664   0.2309   0.1757   0.1056   0.0421     7.78
    3000.      -0.   68.00     2.55   0.1028   0.0372   0.0707   0.2235   0.1788   0.1118   0.0410     7.66
    3250.      -0.   68.00     2.50   0.0980   0.0379   0.0689   0.2198   0.1802   0.1075   0.0390     7.69
    3500.       0.   68.00     2.47   0.1060   0.0368   0.0721   0.2176   0.1788   0.1136   0.0397     7.59
    3750.      -0.   68.00     2.42   0.0964   0.0365   0.0698   0.2164   0.1800   0.1077   0.0368     7.65
    4000.       0.   68.00     2.39   0.1035   0.0364   0.0728   0.2139   0.1785   0.1121   0.0352     7.55
    4250.      -0.   68.00     2.36   0.1044   0.0358   0.0770   0.2130   0.1797   0.1132   0.0391     7.61
    4500.       0.   68.00     2.29   0.0783   0.0377   0.0716   0.2139   0.1767   0.1113   0.0338     7.51
    4750.      -0.   68.00     2.59   0.3036   0.0385   0.0935   0.2137   0.1775   0.2983   0.1333     7.55
    5000.       0.   68.00     3.95   1.2426   0.0487   0.1955   0.2178   0.1761   0.6836   0.5823     7.47
    5250.      -0.   68.00     2.11   0.3633   0.0396   0.0819   0.2160   0.1767   0.1875   0.0605     7.48
    5500.       0.   68.00     2.71   0.4851   0.0427   0.1121   0.2160   0.1752   0.2847   0.1927     7.39
    5750.       0.   68.00     2.31   0.2028   0.0391   0.0880   0.2169   0.1752   0.1701   0.0799     7.42
    6000.       0.   68.00     2.88   0.2951   0.0417   0.0993   0.2193   0.1731   0.2186   0.1272     7.38
    6250.       0.   68.00     2.28   0.2086   0.0378   0.0900   0.2169   0.1726   0.1755   0.0844     7.39
    6500.       0.   68.00     2.19   0.1561   0.0357   0.0869   0.2168   0.1726   0.1522   0.0635     7.35
    6750.       0.   68.00     2.17   0.1760   0.0403   0.0896   0.2156   0.1708   0.1607   0.0620     7.33
    7000.       0.   68.00     2.34   0.3117   0.0513   0.1076   0.2165   0.1695   0.2370   0.1182     7.22
    7500.      -0.   68.00     2.58   0.5684   0.0682   0.1330   0.2160   0.1716   0.3570   0.2965     7.12
    8000.      -0.   68.00     2.54   0.4776   0.0728   0.1399   0.2106   0.1736   0.3618   0.2028     6.49
    8500.       0.   68.00     2.27   0.4055   0.0570   0.1195   0.2022   0.1775   0.2788   0.1427     7.11
    9000.      -0.   68.00     2.03   0.2691   0.0516   0.1101   0.1967   0.1790   0.2157   0.0836     7.16
    9500.       0.   68.00     1.99   0.2788   0.0528   0.1081   0.1838   0.1639   0.2107   0.0934     7.19
   10000.      -0.   68.00     1.49   0.3580   0.0669   0.1215   0.1798   0.1630   0.2563   0.0993     7.09
CONCENTRATION PROFILE, REACH     2     REACH TWO
                 AT TIME   44640.0  OF PERIOD 10

   DISTANCE SALIN.    TEMP     CBOD      NH3      NO2      NO3     PHYT     ZOOP      PON      DON       DO
     FEET     PPT    DEG.F     PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM
       0.      -0.   68.00     1.63   0.3580   0.0664   0.1215   0.1798   0.1630   0.2563   0.0993     7.09
     500.       0.   68.00     1.96   0.4189   0.0733   0.1316   0.1860   0.1687   0.2931   0.1195     7.01
    1000.      -0.   68.00     1.93   0.4143   0.0786   0.1351   0.1891   0.1665   0.2918   0.1156     6.92
    1500.       0.   68.00     1.89   0.3687   0.0689   0.1321   0.1936   0.1722   0.2791   0.1033     6.92
    2000.      -0.   68.00     1.39   0.3609   0.0783   0.1467   0.2156   0.1886   0.2844   0.0944     6.63
    2500.       0.   68.00     1.92   0.3659   0.0764   0.1848   0.2125   0.1854   0.2862   0.0936     6.65
    3000.       0.   68.00     1.72   0.3593   0.0743   0.1874   0.1363   0.1672   0.2743   0.0836     6.76
    3500.      -0.   68.00     1.77   0.3719   0.0798   0.1893   0.1307   0.1696   0.2965   0.0881     6.79
    4000.       0.   68.00     1.53   0.3429   0.0770   0.1877   0.1411   0.1643   0.2721   0.0768     6.81
    4500.      -0.   68.00     1.64   0.3101   0.0609   0.1372   0.1656   0.1568   0.2898   0.0700     7.02
    5000.       0.   68.00     1.46   0.3158   0.0767   0.1643   0.1705   0.1624   0.2619   0.0664     6.86
    5500.       0.   68.00     1.52   0.3392   0.0799   0.1598   0.1743   0.1738   0.2796   0.0718     6.73
    6000.       0.   68.00     1.43   0.3406   0.0819   0.1651   0.1793   0.1737   0.2887   0.0699     6.69
    6500.       0.   68.00     1.56   0.3702   0.0869   0.1780   0.1987   0.1833   0.3081   0.0787     6.58
    7000.       1.   68.00     1.56   0.4158   0.0962   0.1977   0.2060   0.1856   0.3430   0.0913     6.30
    7500.       1.   68.00     1.59   0.4350   0.0983   0.1922   0.1898   0.1811   0.3867   0.1095     6.52
    8000.       1.   68.00     1.51   0.5901   0.0451   0.1356   0.1740   0.1641   0.4756   0.1355     6.47
    8250.       6.   68.00     1.71   0.5765   0.0975   0.2061   0.1902   0.1717   0.4157   0.1800     6.43
    8500.       1.   66.00     1.73   0.6300   0.0975 [illegible]  0.1750 [illegible] [illegible] 0.2109  6.47
```

```
 8750.     11.   68.00    1.82  0.7324  0.0882  0.2153  0.1726  0.1658  0.3770  0.2406     6.70
 9000.     15.   68.30    1.81  0.7248  0.0881  0.2143  0.1664  0.1506  0.4459  0.2506     6.74
 9250.     23.   68.30    1.70  0.6746  0.0872  0.2128  0.1615  0.1572  0.4587  0.2260     6.82
 9500.     38.   68.00    1.50  0.5540  0.0877  0.2020  0.1593  0.1544  0.3995  0.1954     6.86
 9750.     65.   68.00    1.47  0.5373  0.0906  0.2359  0.1610  0.1590  0.3982  0.1528     6.77
10000.    105.   68.00    1.65  0.6527  0.0974  0.2280  0.1687  0.1672  0.4535  0.2000     6.61
10250.    162.   69.00    1.46  0.5215  0.1020  0.2198  0.1707  0.1705  0.3968  0.1274     6.55
10500.    239.   68.00    1.58  0.6062  0.1061  0.2329  0.1718  0.1721  0.4415  0.1635     6.49
10750.    324.   69.00    1.59  0.6062  0.1103  0.2376  0.1782  0.1753  0.4442  0.1570     6.42
11000.    480.   69.00    1.66  0.6509  0.1156  0.2473  0.1773  0.1789  0.4700  0.1719     6.33
11250.    559.   68.00    1.71  0.6769  0.1198  0.2569  0.1802  0.1923  0.4870  0.1781     6.26
11500.    713.   68.00    1.78  0.7069  0.1238  0.2676  0.1935  0.1959  0.5042  0.1875     6.17
11750.    862.   68.00    1.82  0.7258  0.1263  0.2478  0.1889  0.1976  0.5148  0.1932     6.12
12000.   1085.   68.00    1.83  0.7346  0.1277  0.2637  0.1937  0.1865  0.5187  0.1963     6.11
12500.   1399.   68.00    1.90  0.7003  0.1202  0.2578  0.1710  0.1736  0.4910  0.1908     6.30
13000.   1913.   69.00    1.76  0.6551  0.1122  0.2313  0.1509  0.1606  0.4576  0.1783     6.47
13500.   2550.   68.00    1.91  0.6201  0.1059  0.2303  0.1536  0.1538  0.4126  0.1714     6.55
14000.   3505.   68.00    1.99  0.5631  0.0966  0.2005  0.1476  0.1445  0.3419  0.1605     6.65
14500.   4661.   68.00    2.05  0.5182  0.0890  0.1949  0.1372  0.1404  0.3698  0.1564     6.67
15000.   6451.   68.00    2.15  0.4683  0.0808  0.1688  0.1527  0.1393  0.3425  0.1565     6.6[illegible]
15500.   8005.   69.00    2.63  0.4176  0.0722  0.1519  0.1563  0.1370  0.3130  0.1455     6.58
16000.   9973.   68.00    2.94  0.3178  0.0597  0.1351  0.1588  0.1379  0.2678  0.1365     6.6[illegible]
16500.  11371.   68.00    3.16  0.2736  0.0476  0.1036  0.1586  0.1250  0.2209  0.1285     6.65
17000.  12477.   68.00    3.38  0.2022  0.0151  0.0793  0.1548  0.1172  0.1879  0.1184     6.75
17500.  13286.   68.00    3.80  0.1497  0.0260  0.0611  0.1521  0.1090  0.1519  0.1093     6.87
18000.  13508.   68.00    3.81  0.1199  0.0207  0.0505  0.1482  0.1138  0.1145  0.1137     6.96
18500.  13577.   68.00    3.41  0.1116  0.0190  0.0473  0.1468  0.1025  0.1299  0.1024     6.99
19000.  13605.   68.00    3.42  0.1116  0.0190  0.0471  0.1469  0.1024  0.1283  0.1024     6.98
19500.  14955.   68.00    3.66  0.0482  0.0080  0.0259  0.1475  0.0970  0.0920  0.0965     7.05
20000.  15000.   68.00    3.70  0.0400  0.0100  0.0100  0.1500  0.1000  0.1000  0.1000     7.[illegible]
```

APPENDIX II INPUT DATA AND OUTPUT LISTINGS FOR RIVER TEST CASE

II.a Input Data for River Hydrodynamic and Water Quality Solutions

```
TEST CASE HYDRODYNAMICS THROUGHFLOW                                                     Card Group A
           1          1          2          1          2
           1          2          1
           4         75
T                     2          0
CBOD                  0          1
NUTR                  0          1
DO                    0          1          3
           1        384    357120.          3.         10         .05
           2          3
           1          1          1          2
           2          2          2          3
REACH ONE
           1          2          1          1                                               Card Group B
  0.00001                   .018                 10000.     2500.
           1          5     13.0      17.0
  10000.    1000.           0.2                    15.0      1000.
REACH TWO
           2          2          1          1
  .00001                    .018                 20000.     2500.
           1          5     13.0      17.0
  20000.    1000.           0.0                  15.0      1000.
WATER QUALITY DESCRIPTION                                                               Card Group C
T                     0
CBOD                  1
CBOD                0.1     1.047
NUTR                  1          0          5.
           4
   1         0.03
   5         0.18
  12         0.60
  24         0.01
DO                    0
                      1          15
   0.       1000.     2000.      3000.      3500.      4000.      4500.
  5000.     5500.     6000.      6500.      7000.      8000.      9000.
  7000.      8000.      8500.     9000.      9500.     10000.     10500.
   11000.    11500.      12000.     13000.     14000.     15000.    16000.
  17000.     18000.    19000.     20000.
OVERRIDES             2
T                     1
     5000.          68.
CBOD                  1
   5000.            3.0
NH3                   5
0.                   .3
8000.                .3
10000.               1.
12000.               .3
20000.               .3
NO2                   1
      0.0          0.04
NO3                   1
5000.                .5
PHYN                  1
5000.                .2
ZOON                  1
5000.                .2
PON                   5
0.                   .1
8000.                .1
10000.               .5
12000.               .1
20000.               .1
DON                   5
0.                   .1
8000.                .1
10000.               .5
12000.               .1
20000.               .1
DC                    1
       0.0          5.0
  10000.
OVERRIDES              1
T                      1
     5000.           68.
CBOD                   1
   5000.             3.0
NH3                    5
0.                    .3
4000.                 .3
5000.                 1.
6000.                 .3
10000.                .3
NO2                    1
        0.0         0.04
NO3                    1
5000.                 .5
PHYN                   1
5000.                 .2
ZOON                   1
5000.                 .2
PON                    5
0.                    .1
4000.                 .1
5000.                 .5
6000.                 .1
10000.                .1
DCN                    5
0.                    .1
4000.                 .1
5000.                 .5
6000.                 .1
10000.                .1
DO                     1
        0.0          5.0
                       2           25
    0.          10.0.        2000.      3000.      4000.      5000.      6000.
```

```
LATERAL INFLOWS                                                              Card Group D

DESCRIPTION OF INJECTICNS                                                    Card Group E
         2
         1         1    5000.         1         1         5
CBOD      NH3       NC3       PON       DCN
    0.     2502.     1668.    166.8     834.      834.
         2         2   10000.         1         1         5
CBOD      NH3       NO3       PON       DCN
    0.     5004.     3336.    333.6    1668.     1668.
HYDRAULIC DESCRIPTION CF THE NCDES                                           Card Group F
         1         2         1         1
                  0.   1000.
         2         0
         3         2         1         1
                  0.   1000.
HYDRAULIC CUTPUT PARAMETERS                                                  Card Group G
         0
         2
         1         0         1
         2         0         1
WATERQUALITY BOUNDARY CONDITIONS                                             Card Group H
         1         1         1         1
T                          68.
CBOD                        3.
NH3                         .1
NC2                        .04
NO3                        .06
PHYN                       .25
ZCON                       .17
PCN                         .1
DON                        .05
DC                          8.
         2         0
         3         1         1         1
T                          68.
```

```
CBOD                          3.7
NH3                           .06
NO2                           .01
NC3                           .03
PHYN                          .15
ZCON                           .1
PCN                            .1
DCN                           .10
DO                             7.                                      Card Group T
WATER QUALITY OUTPUT

          8
          1       104        1
          2       104        1
          1       112        1
          2       112        1
          1       120        1
          2       120        1
          1       128        1
          2       128        1
```

II.b Partial Output for River Hydrodynamics and Water Quality Solutions

```
****************************************************************************************************

TEST CASE HYDRODYNAMICS THROUGHFLOW

****************************************************************************************************

  HYDRAULIC SOLUTION OPTIONS

       SOLUTION COMPUTATIONS = EXECUTED
       SOLUTION TYPE = STEADY-STATE
       SOLUTION STORAGE = DELETED
       NETWORK TYPE = RIVER
       HYDRAULIC INITIALIZATION FROM TAPE = DELETED

  WATER QUALITY SOLUTION OPTIONS

       SOLUTION COMPUTATIONS = EXECUTED
       SOLUTION TYPE = TRANSIENT
       SOLUTION STORAGE = EXECUTED



   WATER  QUALITY  PARAMETERS        E-TAYLOR MULTIPLE =    75

  TEMPERATURE          CONSTANT
  B.O.D. (CARB.)       CALCULATED
  AMMONIA NITROGEN     CALCULATED
  NITRITE NITROGEN     CALCULATED
  NITRATE NITROGEN     CALCULATED
  PHYTOPLANKTON - N    CALCULATED
  ZOOPLANKTON - N      CALCULATED
  PARTICULATE ORG. - N CALCULATED
  DISSOLVED ORG.  - N  CALCULATED
  DISSOLVED OXYGEN     CALCULATED AS A FUNCTION OF C-BOD & N-BOD

 OUTPUT TO OFFLINE FILES FOR

  B.O.D. (CARB.)
  AMMONIA NITROGEN
  NITRITE NITROGEN
  NITRATE NITROGEN
  PHYTOPLANKTON - N
  ZOOPLANKTON - N
  PARTICULATE ORG. - N
  DISSOLVED ORG.  - N
  DISSOLVED OXYGEN

  SOLUTION TIME PARAMETERS

       NUMBER OF PERIODS =  1                                   LENGTH OF PERIOD = 357120.0
       NUMBER OF HYDRAULIC TIME STEPS PER PERIOD = 384          LENGTH OF HYDRAULIC TIME STEP =    930.0
           MAXIMUM ITERATIONS FOR INITIAL CONDITION =   10
           ERROR TOLERANCE FOR INITIAL CONDITION = [illegible]
            NUMBER OF LEAD-IN PERIODS TO BE READ FROM TAPE =   0
```

```
     NUMBER OF LEAD IN INCREMENTS OF RIVER STUDY =   0
   NUMBER OF WATER QUALITY TIME STEPS PER PERIOD = 128      LENGTH OF WATER QUALITY TIME STEP =   2790.0

NETWORK CONTAINS  2 REACHES WHICH CONNECT  3 JUNCTION AND BOUNDARY NODES               0 CONTROL STRUCTURE(S)

     1   REACH ID =     1          UPSTREAM NODE =  1     DOWNSTREAM NODE =  2
     2   REACH ID =     2          UPSTREAM NODE =  2     DOWNSTREAM NODE =  3
```

```
*****************************************************************************************

   HYDRAULIC DESCRIPTION OF THE REACHES

*****************************************************************************************


DESCRIPTION FOR REACH      1        REACH ONE

     CROSS-SECTION SHAPE = RECTANGULAR PRISMATIC
     BOTTOM SLOPE = CONSTANT
     FRICTION COEFFICIENT = MANNING

     NO ICE COVER

     BOTTOM SLOPE = 0.000010     SIDE SLOPE =  0.0               TOTAL LENGTH OF REACH =     10000.00 FT
     ESTIMATED MESH SPACING =  2500.00 FT
     COMPUTED MESH SPACING =  2500.00 FT
     NUMBER OF HYDRAULIC MESH POINTS =    5
     DATA CROSS-SECTIONS = 1     TABLE ENTRIES =  5     FIRST DEPTH =   13.000 FT     LAST DEPTH =   17.000 FT

     SECTION  1     X =   10000.00 FT     MANNINGS N = 0.0180
                        BOTTOM WIDTH =  1000.00 FT     BOTTOM ELEV =   0.200 FT     RADIUS =  0.0   FT
                        INITIAL SURFACE ELEVATION =  15.000 FT     INITIAL DISCHARGE =    1000.00 CFS
DESCRIPTION FOR REACH      2        REACH TWO

     CROSS-SECTION SHAPE = RECTANGULAR PRISMATIC
     BOTTOM SLOPE = CONSTANT
     FRICTION COEFFICIENT = MANNING

     NO ICE COVER

     BOTTOM SLOPE = 0.000010     SIDE SLOPE =  0.0               TOTAL LENGTH OF REACH =     20000.00 FT
     ESTIMATED MESH SPACING =  2500.00 FT
     COMPUTED MESH SPACING =  2500.00 FT
     NUMBER OF HYDRAULIC MESH POINTS =    9
     DATA CROSS-SECTIONS = 1     TABLE ENTRIES =  5     FIRST DEPTH =   13.000 FT     LAST DEPTH =   17.000 FT

     SECTION  1     X =   20000.00 FT     MANNINGS N = 0.0180
                        BOTTOM WIDTH =  1000.00 FT     BOTTOM ELEV =   0.0   FT     RADIUS =  0.0   FT
                        INITIAL SURFACE ELEVATION =  15.000 FT     INITIAL DISCHARGE =    1000.00 CFS

  ***********************************************************
  *                                                         *
  *    14 STORAGE LOCATIONS REQUIRED FOR HYDRAULIC MESH ARRAYS *
  *                                                         *
  ***********************************************************

  **********************************************
  *                                            *
  *    70 STORAGE LOCATIONS REQUIRED FOR GRAPHS *
  *                                            *
  **********************************************
```

```
*****************************************************************************************************************************************

HYDRAULIC DESCRIPTION OF THE NODES


*****************************************************************************************************************************************


   PRESCRIBED HYDRAULIC BOUNDARY CONDITIONS FOR NODE  1     TYPE = DISCHARGE
         NUMBER OF TABLE ENTRIES =   1     TIME DEPENDENCE = CONSTANT

              TIME (SEC)     SURFACE ELEVATION (FT)     DISCHARGE (CFS)
                 0.0                  0.0                  1000.00

   PRESCRIBED HYDRAULIC BOUNDARY CONDITIONS FOR NODE  2     TYPE = JUNCTION

   PRESCRIBED HYDRAULIC BOUNDARY CONDITIONS FOR NODE  3     TYPE = DISCHARGE
         NUMBER OF TABLE ENTRIES =   1     TIME DEPENDENCE = CONSTANT

              TIME (SEC)     SURFACE ELEVATION (FT)     DISCHARGE (CFS)
                 0.0                  0.0                  1000.00

 ********************************************************************************
 *                                                                              *
 *     2 STORAGE LOCATIONS REQUIRED FOR HYDRAULIC BOUNDARY CONDITIONS           *
 *                                                                              *
 ********************************************************************************



*****************************************************************************************************************************************
```

```
****************************************************************************************************

WATERQUALITY BOUNDARY CONDITIONS

****************************************************************************************************

  PRESCRIBED WATER QUALITY BOUNDARY CONDITIONS FOR NODE  1     TYPE = CONCENTRATION

      NUMBER OF TABLE ENTRIES =   1     TIME DEPENDENCE = CONSTANT

            TABLE ENTRIES FOR TEMPERATURE

                TIME      CONCENTRATION
                 SEC          DEG.F
                  0.    0.680000E+02

            TABLE ENTRIES FOR B.O.D. (CARB.)

                TIME      CONCENTRATION
                 SEC           PPM
                  0.    0.300000E+01

            TABLE ENTRIES FOR AMMONIA NITROGEN

                TIME      CONCENTRATION
                 SEC           PPM
                  0.    0.100000E+00

            TABLE ENTRIES FOR NITRITE NITROGEN

                TIME      CONCENTRATION
                 SEC           PPM
                  0.    0.400000E-01

            TABLE ENTRIES FOR NITRATE NITROGEN

                TIME      CONCENTRATION
                 SEC           PPM
                  0.    0.600000E-01

            TABLE ENTRIES FOR PHYTOPLANKTON - N

                TIME      CONCENTRATION
                 SEC           PPM
                  0.    0.250000E+00

            TABLE ENTRIES FOR ZOOPLANKTON - N

                TIME      CONCENTRATION
                 SEC           PPM
                  0.    0.170000E+00
            TABLE ENTRIES FOR PARTICULATE ORG. - N

                TIME       CONCENTRATION
                 SEC            PPM
                  0.     0.100000E+00

            TABLE ENTRIES FOR DISSOLVED ORG.  - N

                TIME       CONCENTRATION
                 SEC            PPM
                  0.     0.500000E-01

            TABLE ENTRIES FOR DISSOLVED OXYGEN

                TIME       CONCENTRATION
                 SEC            PPM
                  0.     0.800000E+01
PRESCRIBED WATER QUALITY BOUNDARY CONDITIONS FOR NODE  2     TYPE = JUNCTION

PRESCRIBED WATER QUALITY BOUNDARY CONDITIONS FOR NODE  3     TYPE = CONCENTRATION
     NUMBER OF TABLE ENTRIES =    1     TIME DEPENDENCE = CONSTANT

            TABLE ENTRIES FOR TEMPERATURE

                TIME       CONCENTRATION
                 SEC           DEG.F
                  0.     0.680000E+02

            TABLE ENTRIES FOR B.O.D. (CARB.)

                TIME       CONCENTRATION
                 SEC            PPM
                  0.     0.170000E+01

            TABLE ENTRIES FOR AMMONIA NITROGEN

                TIME       CONCENTRATION
                 SEC            PPM
                  0.     0.600000E-01

            TABLE ENTRIES FOR NITRITE NITROGEN

                TIME       CONCENTRATION
                 SEC            PPM
                  0.     0.100000E-01

            TABLE ENTRIES FOR NITRATE NITROGEN

                TIME       CONCENTRATION
                 SEC            PPM
                  0.     0.300000E-01

            TABLE ENTRIES FOR PHYTOPLANKTON - N
     TIME      CONCENTRATION
      SEC           PPM
       0.    0.150000E+00

TABLE ENTRIES FOR ZOOPLANKTON - N

     TIME      CONCENTRATION
      SEC           PPM
       0.    0.100000E+00

TABLE ENTRIES FOR PARTICULATE ORG. - N

     TIME      CONCENTRATION
      SEC           PPM
       0.    0.100000E+00

TABLE ENTRIES FOR DISSOLVED ORG.  - N

     TIME      CONCENTRATION
      SEC           PPM
       0.    0.100000E+00

TABLE ENTRIES FOR DISSOLVED OXYGEN

     TIME      CONCENTRATION
      SEC           PPM
       0.    0.700000E+01

************************************************************************
*                                                                      *
*    2 STORAGE LOCATIONS REQUIRED FOR WATER QUALITY BOUNDARY CONDITIONS *
*                                                                      *
************************************************************************


********************************************************************************************************************
```

```
HYDRAULIC PROFILE, REACH     1     REACH ONE
        AT TIME          0.0  OF PERIOD  1

          X (FT)    SURFACE ELEVATION (FT)      DEPTH (FT)     DISCHARGE (CFS)      VELOCITY (FT/SEC)
              0.             15.08                 14.78            1000.                0.07
           2500.             15.08                 14.81             999.                0.07
           5000.             15.09                 14.83             998.                0.07
           7500.             15.08                 14.86             998.                0.07
          10000.             15.09                 14.88             995.                0.07
HYDRAULIC PROFILE, REACH     2     REACH TWO
        AT TIME          0.0  OF PERIOD  1

          X (FT)    SURFACE ELEVATION (FT)      DEPTH (FT)     DISCHARGE (CFS)      VELOCITY (FT/SEC)
              0.             15.08                 14.88             995.                0.07
           2500.             15.09                 14.91             993.                0.07
           5000.             15.09                 14.93             992.                0.07
           7500.             15.09                 14.96             991.                0.07
          10000.             15.09                 14.98             991.                0.07
          12500.             15.09                 15.01             992.                0.07
          15000.             15.09                 15.03             993.                0.07
          17500.             15.08                 15.06             996.                0.07
          20000.             15.08                 15.08            1000.                0.07
```

Concentration Profile, Reach 1 Reach One At Time

357120.0 of Period 1

```
DISTANCE   TEMP     CBOD     NH3      NO2      NO3      PHYN     ZOPN     POM      DOM      DO
  FEET    DEG.F     PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM      PPM
    0.    68.00     3.00   0.1300   0.0600   0.0533   0.2500   0.1730   0.1000   0.0500    8.00
  500.    68.30     2.93   0.1013   0.0597   0.0620   0.2478   0.1705   0.1025   0.0489    7.94
 1000.    68.00     2.86   0.1335   0.0595   0.0641   0.2447   0.1714   0.1056   0.0477    7.86
 1500.    69.00     2.80   0.1371   0.0596   0.0565   0.2412   0.1730   0.1091   0.0474    7.80
 2000.    69.00     2.74   0.1129   0.0595   0.0691   0.2375   0.1744   0.1161   0.0479    7.73
 2500.    69.00     2.68   0.1222   0.0599   0.0722   0.2338   0.1764   0.1205   0.0499    7.67
```

```
  3000.   68.00    2.56  0.1974  0.0407  0.0761  0.2306  0.1787  0.1305  0.0563    7.60
  3250.   68.00    2.62  0.1693  0.0413  0.0796  0.2291  0.1790  0.1372  0.0587    7.57
  3500.   68.00    2.61  0.1942  0.0421  0.0911  0.2270  0.1797  0.1457  0.0634    7.53
  3750.   68.00    2.63  0.1935  0.0433  0.0962  0.2265  0.1804  0.1563  0.0737    7.50
  4000.   68.00    2.61  0.2385  0.0441  0.0983  0.2259  0.1809  0.1698  0.0868    7.46
  4250.   68.00    2.62  0.2610  0.0454  0.0925  0.2245  0.1815  0.1970  0.0939    7.43
  4500.   68.00    2.65  0.2932  0.0469  0.0991  0.2237  0.1819  0.2092  0.1117    7.39
  4750.   68.00    2.70  0.3379  0.0494  0.1053  0.2230  0.1823  0.2375  0.1356    7.35
  5000.   68.00    2.77  0.4090  0.0501  0.1135  0.2224  0.1827  0.2760  0.1675    7.31
  5250.   68.00    2.74  0.4389  0.0517  0.1153  0.2218  0.1830  0.2749  0.1641    7.27
  5500.   68.00    2.71  0.4386  0.0536  0.1166  0.2212  0.1833  0.2759  0.1605    7.23
  5750.   68.00    2.67  0.4083  0.0550  0.1191  0.2207  0.1836  0.2768  0.1573    7.20
  6000.   68.00    2.64  0.4379  0.0566  0.1198  0.2203  0.1838  0.2778  0.1538    7.16
  6250.   68.00    2.61  0.4375  0.0580  0.1216  0.2198  0.1840  0.2788  0.1507    7.13
  6500.   68.00    2.58  0.4069  0.0595  0.1237  0.2194  0.1843  0.2798  0.1476    7.09
  6750.   68.00    2.56  0.4061  0.0609  0.1250  0.2190  0.1845  0.2808  0.1445    7.05
  7000.   68.00    2.51  0.4356  0.0624  0.1269  0.2187  0.1847  0.2818  0.1413    7.02
  7500.   68.00    2.45  0.4047  0.0648  0.1305  0.2178  0.1854  0.2837  0.1360    6.95
  8000.   68.00    2.39  0.4322  0.0675  0.1347  0.2173  0.1859  0.2858  0.1301    6.88
  8500.   68.00    2.34  0.4304  0.0697  0.1398  0.2164  0.1867  0.2877  0.1252    6.82
  9000.   68.00    2.28  0.3980  0.0721  0.1435  0.2158  0.1873  0.2899  0.1199    6.75
  9500.   68.00    2.23  0.3959  0.0741  0.1480  0.2148  0.1882  0.2918  0.1154    6.69
 10000.   68.00    2.17  0.3931  0.0763  0.1533  0.2141  0.1889  0.2939  0.1106    6.62

CONCENTRATION PROFILE, REACH      2     REACH TWO
                  AT TIME  957120.0  OF PERIOD  1


 DISTANCE  TEMP    CHON     NH3     NO2     NO3    PHYN    ZOON     PON     DON      DO
   FEET   DEG.F     PPM     PPM     PPM     PPM     PPM     PPM     PPM     PPM     PPM
      0.  68.00    2.17  0.3931  0.0763  0.1533  0.2141  0.1889  0.2939  0.1106    6.62
    500.  68.00    2.12  0.3938  0.0780  0.1583  0.2131  0.1898  0.2958  0.1065    6.56
   1000.  68.00    2.07  0.3879  0.0799  0.1642  0.2127  0.1906  0.2980  0.1021    6.49
   1500.  68.00    2.02  0.3854  0.0815  0.1535  0.2111  0.1915  0.2998  0.0984    6.44
   2000.  68.00    1.97  0.3824  0.0832  0.1766  0.2102  0.1922  0.3019  0.0944    6.37
   2500.  68.00    1.93  0.3799  0.0846  0.1827  0.2090  0.1931  0.3037  0.0910    6.31
   3000.  68.00    1.88  0.3766  0.0861  0.1901  0.2080  0.1938  0.3057  0.0874    6.25
   3500.  68.00    1.83  0.3744  0.0873  0.1973  0.2068  0.1947  0.3075  0.0844    6.19
   4000.  68.00    1.79  0.3716  0.0887  0.2056  0.2058  0.1954  0.3096  0.0811    6.12
   4500.  68.00    1.75  0.3596  0.0899  0.2139  0.2045  0.1962  0.3116  0.0786    6.07
   5000.  68.00    1.71  0.3583  0.0912  0.2233  0.2035  0.1969  0.3141  0.0759    6.00
   5500.  68.00    1.67  0.3578  0.0925  0.2329  0.2022  0.1978  0.3167  0.0741    5.93
   6000.  68.00    1.64  0.3667  0.0940  0.2438  0.2012  0.1985  0.3203  0.0726    5.86
   6500.  68.00    1.61  0.3743  0.0956  0.2553  0.2000  0.1994  0.3248  0.0725    5.79
   7000.  68.00    1.58  0.3914  0.0976  0.2683  0.1990  0.2001  0.3318  0.0738    5.71
   7500.  68.00    1.57  0.3992  0.0999  0.2817  0.1978  0.2010  0.3422  0.0785    5.64
   8000.  68.00    1.58  0.4277  0.1032  0.2982  0.1969  0.2017  0.3591  0.0881    5.55
   8250.  68.00    1.59  0.4500  0.1051  0.3072  0.1962  0.2021  0.3711  0.0962    5.50
   8500.  68.00    1.61  0.4733  0.1074  0.3176  0.1958  0.2025  0.3865  0.1070    5.45
   8750.  68.00    1.65  0.5177  0.1103  0.3296  0.1952  0.2029  0.4063  0.1219    5.40
   9000.  68.00    1.70  0.5576  0.1139  0.3409  0.1948  0.2033  0.4318  0.1419    5.36
   9250.  68.00    1.78  0.6176  0.1162  0.3550  0.1943  0.2037  0.4647  0.1689    5.29
   9500.  68.00    1.89  0.7170  0.1200  0.3716  0.1939  0.2041  0.5072  0.2067    5.22
   9750.  68.00    2.02  0.8244  0.1238  0.3933  0.1935  0.2045  0.5670  0.2529    5.16
  10000.  68.00    2.21  0.9582  0.1279  0.4129  0.1931  0.2049  0.6331  0.3167    5.10
  10250.  68.00    2.18  0.9579  0.1319  0.4211  0.1926  0.2053  0.6329  0.3098    5.03
  10500.  68.00    2.15  0.9573  0.1354  0.4297  0.1922  0.2057  0.6328  0.3028    4.97
  10750.  68.00    2.13  0.9562  0.1395  0.4393  0.1917  0.2061  0.6325  0.2963    4.90
  11000.  68.00    2.11  0.9551  0.1433  0.4473  0.1913  0.2064  0.6322  0.2895    4.84
  11250.  68.00    2.09  0.9540  0.1468  0.4562  0.1909  0.2068  0.6318  0.2834    4.77
  11500.  68.00    2.06  0.9526  0.1506  0.4655  0.1905  0.2072  0.6314  0.2769    4.71
  11750.  68.00    2.04  0.9511  0.1546  0.4746  0.1900  0.2076  0.6309  0.2739    4.64
  12000.  68.00    2.01  0.9493  0.1573  0.4841  0.1896  0.2079  0.6303  0.2667    4.58
  12500.  68.00    1.97  0.9557  0.1627  0.5024  0.1886  0.2087  0.6288  0.2560    4.46
  13000.  68.00    1.93  0.9507  0.1688  0.5219  0.1860  0.2093  0.6271  0.2423    4.33
  13500.  68.00    1.91  0.9556  0.1747  [illegible]  [illegible]  0.2130  0.6249  0.2325    4.22
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14000.	68.00	1.45	0.9142	0.1749	0.5535	0.1866	0.2134	0.6274	0.2219	4.39
14500.	68.00	1.81	0.9126	0.1928	0.5770	0.1953	0.2110	0.6192	0.2130	3.99
15000.	68.00	1.78	0.8737	0.1908	0.5868	0.1946	0.2112	0.6155	0.2037	3.89
15500.	68.00	1.75	0.9143	0.1935	0.5339	0.1835	0.2114	0.6136	0.1959	3.79
16000.	68.00	1.73	0.8014	0.1917	0.6735	0.1927	0.2110	0.6044	0.1969	3.73
16500.	68.00	1.71	0.9960	0.1776	0.6371	0.1813	0.2103	0.5957	0.1784	3.55
17000.	68.00	1.72	0.4535	0.1914	0.6354	0.1921	0.2285	0.5836	0.1698	3.62
17500.	68.00	1.75	0.8927	0.1876	0.6791	0.1793	0.2054	0.5454	0.1622	3.66
18000.	68.00	1.82	0.7462	0.1796	0.6052	0.1762	0.1996	0.5377	0.1539	3.79
18500.	68.00	1.98	0.7131	0.1437	0.5557	0.1733	0.1900	0.4926	0.1464	4.26
19000.	68.00	2.27	0.5845	0.1362	0.6549	0.1685	0.1736	0.4195	0.1333	4.56
19500.	68.00	2.79	0.3919	1.0376	0.3042	0.1614	0.1462	0.3005	0.1199	5.66
20000.	68.00	1.73	0.3500	0.3100	0.3333	0.1510	0.1000	0.1000	0.1009	7.00